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APTI (Air Pollution Training Institute) Course 450 Source Sampling for Particulate Pollutants, Instructor's Guide

Northrop Services, Inc.
Research Triangle Park, NC

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16. ABSTRACT

The Instructor's Guide for Air Pollution Training Institute Course 450 "Source Sampling for Particulate Pollutants" contains guidelines for conducting a four and one-half day course in source sampling. The Guide contains lesson plans, laboratory instructions, exams, copies of handout materials, and solutions to problem sets. The lesson plans include keys to APTI audio visual materials and suggested instructional techniques. These materials are intended for use in conjunction with Student Manual EPA 450/2-79-006 and Student Workbook EPA 450/2-79-007.

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a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Collection	Filtered Particle Sampling	Particle Measurement	14 D
Air Pollution			
Gas Sampling			
Dust			

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Air

EPA

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Instructor's Guide

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APTI
Course 450
Source Sampling for Particulate Pollutants

Instructor's Guide

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Notice

This is not an official policy and standards document. The opinions, findings, and conclusions are those of the authors and not necessarily those of the Environmental Protection Agency. Every attempt has been made to represent the present state of the art as well as subject areas still under evaluation. Any mention of products or organizations does not constitute endorsement by the United States Environmental Protection Agency.

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AIR POLLUTION TRAINING INSTITUTE
MANPOWER AND TECHNICAL INFORMATION BRANCH
CONTROL PROGRAMS DEVELOPMENT DIVISION
OFFICE OF AIR QUALITY PLANNING AND STANDARDS

The Air Pollution Training Institute (1) conducts training for personnel working on the development and improvement of state, and local governmental, and EPA air pollution control programs, as well as for personnel in industry and academic institutions; (2) provides consultation and other training assistance to governmental agencies, educational institutions, industrial organizations, and others engaged in air pollution training activities; and (3) promotes the development and improvement of air pollution training programs in educational institutions and state, regional, and local governmental air pollution control agencies. Much of the program is now conducted by an on-site contractor, Northrop Services, Inc.

One of the principal mechanisms utilized to meet the Institute's goals is the intensive short term technical training course. A full-time professional staff is responsible for the design, development, and presentation of these courses. In addition the services of scientists, engineers, and specialists from other EPA programs governmental agencies, industries, and universities are used to augment and reinforce the Institute staff in the development and presentation of technical material.

Individual course objectives and desired learning outcomes are delineated to meet specific program needs through training. Subject matter areas covered include air pollution source studies, atmospheric dispersion, and air quality management. These courses are presented in the Institute's resident classrooms and laboratories and at various field locations.

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INTRODUCTORY MATERIALS FOR
COURSE 450 - SOURCE SAMPLING FOR PARTICULATE POLLUTANTS

This Instructor's Guide is to provide you as Course Moderator with assistance in the preparation and presentation of Course #450 - Source Sampling for Particulate Pollutants. It will provide you with guidelines, instructions and some general information that should facilitate your efforts in staging this course.

I. Course Description

Course 450 - Source Sampling for Particulate Pollutants is designed as a four and one half day laboratory course for students of science and engineering background. The course presents the principles and techniques necessary for performing isokinetic source sampling procedures for particulate matter given in the EPA Reference Method 5 of the Federal New Source Performance Standards. It should prepare engineers and technicians to perform and/or evaluate a particulate source test. Lectures cover formulas describing basic fluid dynamics involved in isokinetic sampling and students are given experience in problem solving and application using EPA Reference Methods 1, 2, 3, 4, and 5. Laboratory exercises are designed to familiarize students with the proper use and calibration of source sampling equipment. Students perform a source test, make all calculations, and report results. Major topics include:

- Basic Theories
- Description and Analysis of Source Sampling Equipment
- Explanation of EPA Method 1-5
- Source Sampling Calculations
- Isokinetic Source Sampling Principles
- Gas Velocity, Molecular Weight, and Volumetric Flow Rate Measurement
- Laboratory Particulate Source Test
- Introduction to Alternate Methods of Particulate Analysis

II. Background, Origin, and Philosophy

The Environmental Protection Agency Air Pollution Training Institute (APTI) provides courses in air pollution control technology, ambient and source monitoring, and air quality management. In July, 1976 Northrop Services, Inc. was contracted to both present Training Institute courses and to provide support and technical services for the Institute as a whole. Source sampling and other laboratory courses of particular importance to governmental and industrial personnel concerned with air pollution problems received early efforts of instructional development to design the best possible training experiences for the students. This required thorough examination of both the materials for instruction and an examination of the characteristics of the student audience. From such studies, the courses have been revised and developed to provide training that enables every student to achieve the specific course objectives.

The demographic characterization of students attending source sampling classes has shown the following:

TABLE I

Employer	Course 450
Federal EPA	16%
Other Federal	5
State Government	12
Local Government	14
Industry	45
Consultant	6
Other	2

TABLE II

Occupation	Course 450
Administrator	3%
Chemist	14
Engineer	44
Ind. Hygenist	1
Phys. Scientist	3
Sanitarian	3
Technician	28
Other	4

TABLE III

Educational Background	Course 450
High School	24%
Bachelor	56
Master	18
PhD	2

TABLE IV

Years Experience	Course 450
0 - 1 years	48%
2 - 4	31
5 - 7	15
8 - 10	3
> 10	3

Student intellectual characteristics were determined early in the initial contract year through standardized ability testing given to a total of 186 individuals in 10 different courses offered by the Institute. The Course #450 sample produced the following percentile rank scores:

	Percentile Rank
Verbal ability	78
Numerical	70
Spatial	35
Reasoning	51
Memory	47

The characterization studies mentioned above have indicated that for APTI source sampling courses, the course content and instructional methods should be explicit rather than implicit. Although formal educational level tends to be generally high, the ability testing has indicated the need for the course content to be presented in a careful and logical order with the underlying principles and relationships of given concepts being taught directly. At critical junctures where students are required to visualize a concept, infer a relationship, or visualize an added dimension, instruction is mediated with the use of:

- Graphic illustrations usually in the form of 35 mm slides,
- Lecture demonstrations,
- Inclass problem-solving,
- Hands-on laboratory experience
- Constant repetition and review of fundamental concepts.

Course #450 is designed to teach the principles of isokinetic sampling to the engineer who finds it necessary to either conduct or to observe a stack test.

A stack tester normally stays in this type of work for 2 or 3 years before moving on to another position. This creates a continual need to train new people entering this field of work. Students attending #450 have ranged from high school graduates to Ph.D.'s involved in research work. The average student (see Tables II and III) has a bachelor's degree and is employed as a technician or an engineer. In this course, 50% of the students come from industry and 50% come from governmental agencies (this creates a forum for interesting discussions within the course presentations). Most of the students are also just entering the field of air pollution, 48% having less than one year of experience. The approach taken in instructing Course #450, is to direct the level of instruction towards the engineer with four years of college, newly entering the field of air pollution. Through the use of discussion sessions, those less prepared and those with more experience are provided the opportunity to supplement their learning in the course. This approach has succeeded, with most students gaining the knowledge they desired upon entry into the course.

The variety of activities that the student experiences in Course #450 aides in the assimilation of a great deal of knowledge in a short time. The first 3 days of the Course are very rapidly paced and produce some stress in the students. The fourth and fifth day are conducted at a slower pace, still with a variety of activities, but with more opportunity for questioning and discussion. Here, the content of the first 3 days is reinforced and refined. Every effort is made to answer any question asked by a student, even at the expense of some of the more advanced members of the class. In fact, it has often occurred that the simpler questions lead into details that the class as a whole finds valuable. At the opposite end, the more complex questions, give the beginning stack sampler an opportunity to realize the complexities that can arise in performing the sampling method.

III. Instruction for Preparation and Presentation of Course

A. Responsibilities of Course Moderator

This course generally requires 4½ days for a complete presentation. It can also be expected that anywhere from 35 to 60 hours of additional preparation will be required by the individual designated Course Moderator. Preparation and continuity are the principle responsibilities of the Course Moderator who will coordinate all on-site activities both before and during the course presentation. The following lists the actual tasks that are considered the direct responsibility of the Course Moderator:

1. Scheduling the course presentation.
2. Recruiting (hiring) and briefing instructors.
3. Preparation of classroom and teaching facilities.
4. Preparation of and distribution of course materials.
5. Presentation of introduction and other appropriate lectures.
6. Maintaining continuity throughout the course.

B. Scheduling

The course itself is designed around a format using 18 lectures and 3 laboratory sessions, all of which are designed to fit into a 4½ day time frame of morning and afternoon sessions. Because the course contains a concentrated level of involvement with rather technical material, it is recommended that no more than seven (7) hours of class instruction be presented in one day.

The course materials contain 21 segments each listed below with its recommended time and schedule placement.

Proposed Sequence	Lesson Title	Expected Time Required
Day #1		
Lesson #1	Welcome and Registration	30 minutes
Lesson #2	Introductfon to Source Sampling	1 hr 15 min
Lesson #3	EPA Method 5 Sampling Train	1 hour
Lesson #4	Discussion of Labaoratory Exercises	1 hour 30 min
Laboratory #1	Lab Exercises	2 hours 30 min
Day #2		
Lesson #5	Isokinetic Source Sampling	1 hour 15 min
Lesson #6	Setting the Isokinetic Sampling Rate	1 hour 15 min
Lesson #7	Discussion of Laboratory Exercises	2 hours 45 min
Laboratory #2	Orsat Laboratory	1 hour 30 min

Day #3

Lesson #8	Calculations and Interpretation of % Isokinetic	1 hour 45 min
Lesson #9	Definition of a Particulate	15 min
Lesson #10	Discussion of Source Sampling Exercise	1 hr 15 min
Laboratory #3	RM5 Testing	3 hours

Day #4

Lesson #11	Concentration Corrections	1 hour 15 min
Lesson #12	Literature Sources	30 min
Lesson #13	F-Factor Method	1 hour
Lesson #14	Calculation Review	1 hour 45 min
Lesson #15	Error Analysis	30 min
Lesson #16	Source Sampling Quality Assurance and Safety on Site	1 hour 20 min

Day #5

Lesson #17	Particulate Sizing Using Cascade Impactor	1 hour
Lesson #18	Transmissometers	1 hour 15 min

C. Instructors

The four most important criteria in the selection of faculty for this course are:

1. A knowledge of the methods and procedure in particulate sampling.
2. Practical experience with a facility providing stack sampling.
3. Experience (and ability) to instruct adults using traditional and non-traditional methods, materials and techniques.
4. A positive attitude toward air quality management.

Before instructors are actually involved with instruction in the classroom the course moderator should conduct thorough briefing and preparation sessions in which an overview of the entire course presentation is given. Specific discussion of course and lesson objectives should result in an assurance that the instructor is well prepared and familar with the materials, procedures, and techniques that they will be using.

The course moderator should stress the difference in the role that the instructor plays as compared to traditional university instruction situations. All instructors should fully understand the function of course and lesson objectives and the relationship of each objective to their particular materials and to the pre and post testing.

It may be particularly helpful to the instructors if they are able to sit in on early sessions of the course presentation, so that they get a feel for the way the students are oriented to the material and be able to incorporate the strengths and background experiences of the students into the various instructional sessions.

Preparation must be stressed to all prospective instructors. Thorough familiarization with all the prepared materials is essential for even "expert" instructors. Laboratory sessions require additional preparation and should include a complete run-through to check out the methods and equipment before ever presenting them to the students. Remember that Murphy's law will always hold true in a student laboratory exercise: "What ever can go wrong, will!"

D. Physical Setting

Room size: 1300 square ft/24 students
Seating arrangement: Double tables, 6-8 student/table
Audio visual requirements: 35 mm slide projector, overhead projectors, large screen
Lecture paraphernalia: Lighted lectern, blackboard, chalk
Laboratory room requirements: 700 sq ft, electricity, analytical balances.

E. Course Materials

In addition to the lesson outlines and audio-visual materials, the Instructional Resource Materials for Course 450 include copies of the following items needed for distribution to the student:

1. APTI Student Manual: "Source Sampling for Particulate Pollutants", EPA 450/2-79-006
2. APTI Student Workbook, EPA 450/2-79-007
3. Pre-test
4. Post-test
5. EPA Pamphlet - "Need Air Pollution Information", June 1979
6. Handout - reprint of article - Leland, Bernice J; Hall, Jerry L. "Correction of S-Type Pitot - Static Tube Coefficients When Used for Isokinetic Sampling from Stationary Sources." Environmental Science and Technology 11:694-700; July, 1977.
7. Handout - reprint of article - Midgett, M. Rodney. "How EPA Validates NSPS Methodology." Environmental Science and Technology 11:655 - 659; July 1977.
8. Handout - A Monograph - Shigehara, R. T. "A Guideline for Evaluating Compliance Test Results."
9. Handout - Calculation Form for Method 5 Particulate Test
10. Federal Register - Vol. 42, No. 160, August 18, 1977 "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8."
11. Federal Register - Vol. 43, No. 37, February 23, 1978, Part V "Kraft Pulp Mills."

F. Lesson Plan Use

Each lesson plan module is designed to serve as:

- A. Source of lesson objectives
- B. Content guide for instructor
- C. Lecture outline
- D. Directions for use of visual aids
- E. Guidelines for approach to the lesson.

Each lecture plan outline is carefully timed. Instructors should give attention to observing time schedules, and to becoming familiar with the "pace" of the lessons to be given.

Instructors must be familiar with the visual aids and handout materials before attempting to present any lesson.

Instructors may wish to vary slightly from the format or content for a given lesson but should be cautioned that schedules and lesson objectives must be maintained. Variations should be in the direction of greater student participation. Instructors should remember that the final exam reflects the lesson objectives as presented through these lesson outlines.

G. Audio-Visual Materials

The visuals for course 450 include 153 35mm slides. The slides are keyed using number references that are also found on the slide. The number identifies the lecture and sequence of the slide. Thus L2-16 identifies a slide in lecture 2 that comes before L2-17 and after L2-15. Some slides that are part of sequences are followed by a letter, thus L2-2a, L2-2b, and L2-2c are all members of a particular sequence.

The specific lessons are as follows:

Lesson 1	no slides	
Lesson 2	20 slides	L2-1a through 2-14
Lesson 3	no slides	Use L7-4, L7-5
Lesson 4	no slides	
Lesson 5	4 slides	L5-1 through L5-4
Lesson 6	21 slides	L6-1 through L6-21
Lesson 7	35 slides	L7-1 through L7-35
Lesson 8	12 slides	L8-1 through L8-12
Lesson 9	no slides	
Lesson 10	no slides	
Lesson 11	7 slides	L11-1 through L11-7
Lesson 12	6 slides	L12-1 through L12-6
Lesson 13	10 slides	L13-1 through L13-10
Lesson 14	no slides	
Lesson 15	3 slides	L15-1 through L15-3
Lesson 16	1 slide	L16-1
Lesson 17	6 slides	L17-1 through L17-6
Lesson 18	28 slides	L18-1 through L18-27

H. Grading Philosophy

The APTI guidelines for grading student's performance in "Source Sampling for Particulate Material" and granting Continuing Education Units (CEU's) are as follows:

The student must:

- attend a minimum of 95% of all scheduled class and laboratory sessions;
- complete and hand in copies of all laboratory data derived in the laboratories; and
- achieve an average course grade of 70% or better derived as follows:
    1) 90% from final examination
    2) 10% from laboratory performance

I. Other Logistics

Since the Course Moderator will need to consider a great variety of logistic and instructional concerns, the following checklist is provided to serve as a guide to meeting these responsibilities.

The course developers have tried to provide you with as much information and materials as possible to enable you to present a unique and exciting educational venture.

GOOD LUCK.

CHECKLIST
of Activities
For Presenting the Course

A. Pre-Course Responsibilities:

____ 1. Reserve and confirm classroom(s), including size, "set-up," location and costs (if any).

____ 2. Contact and confirm all faculty (speakers) for the course(s), including their A-V requirements. Send material to them.

____ 3. Reserve hotel accommodations for faculty.

____ 4. Arrange for and confirm food service needs (i.e., meals, coffee breaks, water, etc).

____ 5. Prepare and reproduce final ("revised" if appropriate) copy of the detailed program schedule.

____ 6. Reproduce final registration/attendance roster, including observers (if any).

____ 7. Prepare name badges and name "tents" for students and faculty.

____ 8. Identify, order, and confirm all A-V equipment needs.

____ 9. Prepare two or three 12 in. x 15 in. signs on posterboard for posting at meeting area.

____ 10. Arrange for and confirm any special administrative assistance needs on-site for course, including "local" Address of Welcome, etc.

____ 11. Obtain copies of EPA Manuals, and Pamphlets.

____ 12. Pack and ship box of supplies and materials one week prior to beginning of course (if appropriate).

____ 13. Arrange and confirm the availability of satisfactory laboratory equipment and facilities. (See list following and lab descriptions in rear of this manual)

____ 14. Set up needed equipment in the laboratory setting and make sure all equipment and instruments are operating correctly.

____ 15. Have run-through of lab exercise with instructors.

CHECKLIST (Cont.)

B. On-Site Course Responsibilities

_____ 1. Check on and determine final room arrangements (i.e., tables, chairs, lectern, water, cups, etc.)

_____ 2. Set up A-V equipment required each day and brief operator (if supplied).

_____ 3. Post signs where needed.

_____ 4. Alert receptionist, phone operator(s), watchmen, etc. of name, location, and schedule of program.

_____ 5. Conduct a new speaker(s) (i.e., instructor) briefing session on a daily basis.

_____ 6. Verify and make final food services/coffee arrangements (where appropriate).

_____ 7. Identify and arrange for other physical needs as required (i.e., coat racks, ashtrays, etc).

_____ 8. Make a final check on arrival of guest speakers (instructors) for the day.

_____ 9. If there is lab work on a real stack, find out how to call the local life squad or similiar service, in case an accident occurs.

C. Post-Course Responsibilities

_____ 1. Return the following to APTI: (If APTI course):
- Student Registration Cards
- Pre-Test Answer Sheets — Graded
- Post-Test Answer Sheets — Graded
- Laboratory Data Summary Sheets from each student
- Student Course Critiques

_____ 2. Prepare Course Director Report including pertinent comments on the presentation. (If APTI course)

_____ 3. Request honorarium and expense statements from faculty; order and process checks.

_____ 4. Write thank-you letters and send checks to paid faculty.

_____ 5. Write thank-you letters to non-paid guest speakers.

_____ 6. Prepare evaluation on each course (including instructions, content, facilities, etc).

_____ 7. Make sure A-V equipment is returned.

_____ 8. Return unused materials to your office.

COURSE #450

SOURCE TESTING FOR PARTICULATE POLLUTANTS

COURSE GOAL

The major goal of Course #450, "Source Sampling for Particulate Pollutants", is to provide the student with a basic understanding of the theory and experimental methods involved in isokinetic sampling, the foundation of EPA Method 5.

Knowledge of isokinetic sampling, serving as the core of the course material, will then be amplified with lectures, problem sessions and lecture-demonstrations in order to present the many facets of particulate sampling. Upon completion of the course, the student should be able to design and plan a source test, perform all of the calculations involved in reporting a mass emission rate, and understand problems of error and quality assurance. The student should also become conversant with the methods of particle sizing and transmissometry. He should attain an awareness of the problems involved in source sampling and be able to recognize what constitutes difficult experimental situations, a good test, good data, and a good final report.

COURSE OBJECTIVES

On completion of this course the student should be able to:

- Define symbols and common source sampling terms used in source sampling for particulate pollutants.
- Recognize, interpret and apply sections of the Federal Register pertinent to source sampling for particulate pollutants.
- Understand the construction, operation and calibration of component parts of the Federal Register Method 5 sampling train.
- Recognize the advantages and disadvantages of the nomograph and its uses in the establishment of the isokinetic sampling rate.
- Understand the "working" isokinetic rate equation and its derivation.
- Define isokinetic sampling and illustrate why it is important in sample extraction.
- Apply Federal Register Methods 1 through 4 in preparation for a particulate sampling test.
- Understand the construction, evaluation, standardization, and orientation of the "S Type" pitot tube and its application to source sampling.
- Calculate the "Percent Isokinetic" value for a source test, and interpret the effect of over or under-isokinetic values on the source test results.
- Understand the quality assurance programs involved in source sampling dealing with nozzle sizing, orifice meter calibration, nomograph standardization and sample recovery.
- List the steps involved in conducting a source test, including completion of pre-test and post-test forms. The student should be able to recognize potential problem areas in preparing and conducting a source test.

COURSE OBJECTIVES - Continued

- Properly assemble, leak check, conduct and recover a Method 5 sample according to Federal Register, August 18, 1977.
- Apply Federal Register Method 3 gas analysis in formulating the stack gas molecular weight and % excess air.
- Explain the principles behind the operation of particle sizing devices for sources and name some of those devices being tested by EPA.
- Define the terms opacity, transmittance and transmissometer.
- Recognize the relationship between optical density and particulate concentration.

LABORATORY EQUIPMENT LIST FOR 24 STUDENTS

COURSE 450

SOURCE SAMPLING FOR PARTICULATE POLLUTANTS

GENERAL EQUIPMENT FOR SOURCE TEST

24	nomographs
4	meter boxes
4	sample boxes
4	umbilical cords
4	sets of glassware
4	probes
4	filter holders, frits
4	pre-weighed filters
4	containers of silica gel (200g each)
6	extension cords
4	folding wood rulers
2	calipers
1	ice chest
4	funnels
2	250ml graduated cylinders
8	stopwatches
2	boxes kaydry towels
4	tweezers
4	probe wrenches - 3/4" and 1" open end wrenches
1	spare filter set-up
2	sets of spare glassware
	miscl. tools
4	rolls duct tape
	ice
	flyash

TESTING FACILITY - see Laboratory 1 for diagrams.

2060 CFM Squirrel Cage blower with 3/4 HP motor
12" diameter galvanized duct work

6	5 foot sections
4	2 foot sections
3	elbows
2	adapters; 1 to reduce 14" diameter fan inlet to 12" diameter; 1 section to adapt rectangular fan outlet to 12" diameter.

PITOT TUBE EXPERIMENT

4	standard pitot tubes
4	inclined manometers, (oil, reading to at least 6" H_2O)
4	sets of manometer lines w/connectors
8	ring stands each with 3 finger clamps

WET BULB-DRY BULB EXPERIMENT

2 beakers with water
4 thermometers (to 300°F)
2 wicks

M.W. EXPERIMENT

4 Orsats

SAMPLE AGENDA

Name and address of
agency conducting course

(Dates of course)

450 SOURCE SAMPLING FOR PARTICULATE POLLUTANTS

Acknowledgement
of role of other
agencies, if any,
in conduct or
support of
presentation.

Course location

Name of course
Director

DAY & TIME	SUBJECT	SPEAKER
MONDAY		
8:30	Welcome and Registration	
9:00	Pretest	
9:45	Introduction to Source Sampling	
	1. Objectives	
	2. Definitions	
	3. Pollutant Mass Rate	
	4. Gas Physics	
10:30	EPA Method 5 Sampling Train	
11:30	LUNCH	
12:15	Discussion of Laboratory Exercises	
	1. Sample & Velocity Traverses for Stationary Sources	
	2. Determination of Stack Gas Velocity and Volumetric Flow Rate	
	3. Wet Bulb-Dry Bulb Moisture Estimation	
	4. Orifice Meter Calibration	
1:45	Travel to Source Simulator	

If course is not conducted by EPA, but EPA/APTI materials are used, it would be appreciated that an acknowledgement appear here.

DAY & TIME	SUBJECT	SPEAKER
MONDAY (Continued)		
2:00	Laboratory Exercises	
	Station #1. Traverse Point Determination	
	Station #2. Pitot Tube Calibration	
	Station #3. Moisture Estimate	
	Station #4. Calibration of Orifice Meter	
HOMEWORK:	1. Complete Laboratory Exercises Calculations	
	2. Read Example Problems - Workbook pp. 165-174	
	3. Work Problems 1, 2, and 3 - Additional Problem Section pp. 177-178	
TUESDAY		
8:30	Isokinetic Source Sampling	
9:45	Setting the Isokinetic Sampling Rate	
11:30	LUNCH	
12:15	1. Review of Sample and Velocity Traverses	
	2. Reference Method Determination of Moisture in Stack Gas	
	3. Gas Analysis for Carbon Dioxide, Excess Air and Dry Molecular Weight	
3:00	Orsat Laboratory	
HOMEWORK:	1. Do Problems 1, 2, and 3 - Setting Isokinetic Sampling Rate p 57	
	2. Work Problems 4, 5, and 6 - Additional Problems Section pp 179-181	
WEDNESDAY		
8:30	Calculation and Interpretation of % Isokinetic	
	1. Equations for % Isokinetic	
	2. Evaluating Anisokinetic Source Test Results	
10:15	Definition of a Particulate	
10:30	BREAK	

DAY & TIME	SUBJECT	SPEAKER
WEDNESDAY (Continued)		
10:45	Discussion of Source Sampling Exercise 1. Experiment Design 2. EPA Method 5 3. Report Writing	
12:00	LUNCH	
12:45	Travel to Source Simulator	
1:00	Stack Test	
HOMEWORK:	Complete Stack Test Data Summary Form	
THURSDAY		
8:30	Concentration Corrections Class Problems	
10:00	Literature Sources	
10:30	F-Factor Method	
11:30	LUNCH	
12:15	1. Calculation Review - Hand in Stack Test Data Summary 2. Discussion of Laboratory Results 3. ERROR Analysis	
2:30	Source Sampling Quality Assurance and Safety on Site	
HOMEWORK:	Read Manual Selections	
FRIDAY		
8:30	Particle Sizing	
9:30	Transmissometers	
10:45	Post Test and Closing	

The Course closes at 12:00 a.m. on Friday, please plan to remain until that time.

Three Continuing Education Units (CEU's) will be awarded to those students who attend a minimum of 95% of all scheduled class and laboratory sessions and who satisfactorily pass examinations based on studies and assignments.

SOURCE SAMPLING FOR PARTICULATE EMISSIONS
APTI COURSE NUMBER 450

PRETEST

DIRECTIONS: Circle the best answer (there is one and only one correct answer for each question). Mark answers both on your Exam Sheet and on the Answer Sheet. You will be asked to turn in only the Answer Sheet. (The August 18, 1977 Federal Register and a scientific calculator may be used during this test. You should take no more than 45 minutes.)

1. How would you correct the "C" factor of your nomograph if your pitot tube had a coefficient of C_p = .79?

   a. Take $C^{corr}_{nomog} = 0.85/0.79 C_{nomog}$

   b. Use $C^{corr}_{nomog} = \frac{0.79}{0.85} C_{nomog}$

   c. The nomograph can't be corrected for a different C_p.

   d. Use $C^{corr}_{nomog} = \frac{(0.79)^2}{(0.85)^2} C_{nomog}$

2. The **Type S** pitot tube has demonstrated several characteristics that are important in understanding its proper function and application in measuring gas velocity. Those characteristics which can affect its performance are:

   a. Tube length and diameter
   b. Sensing area and tube length
   c. Sensitivity to turbulence and orientation
   d. Sensitivity to temperature variation and abusive environments

3. What assumptions does the nomograph make about the stack gas molecular weight?

   a. The molecular weight can be corrected for %CO_2 and %O_2.
   b. The dry stack gas molecular weight is measured to be 29.
   c. The molecular weight (wet) is assumed to be 29.
   d. The stack gas molecular weight is directly related to v_s, the stack gas velocity.

4. Correcting pollutant concentrations to 12% CO_2 is applicable to:

   a. Non-combustion processes
   b. All chemical processes except oil refineries
   c. Combustion processes
   d. Only those processes burning No. 2 diesel oil

5. If the particulate concentration is measured as 0.1 grains per dry standard cubic foot (DSCF), and the stack gas flow rate is 70,000 DSCF per minute, what is the particulate emission rate in pounds per hour (7000 grains = 1 pound)?

   a. 60 pounds/hour
   b. 1 pound/hour
   c. 10 pounds/hour
   d. Need more information

6. If the gas analysis is 6.2% 0_2, 14.2% $C0_2$, 0% C0, 79.6%N_2 and the % H_20 is 7.0%, the wet molecular weight of this mixture is:

   a. 29.6
   b. 23.8
   c. 9.0
   d. 30.9

7. The greatest source of experimental error for a stack test arises out of the measurements for:

   a. Moisture content of the stack gas
   b. Molecular weight of the stack gas
   c. Velocity of the stack gas
   d. Sample point position within the duct

8. The most important aspect of a safety evaluation procedure designed to prevent accidents is a continuous:

   a. Reminder to personnel of previous accidents
   b. Accident analysis program
   c. Safety indoctrination program
   d. Stronger enforcement of safety rules

9. The on-site sampling team should follow:

   a. Their developed safety methods
   b. Plant safety regulations and those guidelines given in the CRC safety handbook
   c. All plant safety guidelines in addition to those developed specifically for the sampling team
   d. Posted plant regulations

10. The Glass Fiber Filter used in Method 5 particulate sampling must:

    a. Exhibit at least 96.5% collection efficiency
    b. Be dessicated 24 hours and weighed to a constant weight
    c. Be dessicated 24 hours and weighed to the nearest 1.0 mg
    d. Be dessicated 6 hours and weighed

11. Turbulence is created by any accessory adjacent to the Type S pitot tube. The effect of turbulence upon the calibration of the Type S pitot tube is minimized when the accessory is separated from the pitot tube by a distance:

a. 7.62 mm
b. 3/4"
c. 2"
d. 3"

12. The term $\Delta H_@$ is defined as:

a. The sum of the stagnation pressure and static pressure in the duct.
b. The flow rate of dry air flowing through a flat, sharp-edged orifice
c. Sampling Meter Console calibration factor
d. The pressure differential across the sampling console orifice meter that creates a flow rate through the meter of 0.75 cfm dry air at 70°F and 29.92 in. Hg.

13. The Type S pitot tube must be properly oriented in the gas stream if it is to measure the correct gas velocity impact pressure. A serious drawback of sampling probe design in some equipment systems is:

a. The pitot tube is permanently welded to the sampling sheath
b. The pitot tube-probe sheath assembly can be accidently twisted into misalignment in the gas stream
c. The pitot tube is constructed of 316 stainless steel
d. The pitot tube-probe sheath assembly is out of round

14. Blowers are necessary on transmissometers to:

a. Prevent mirror lock-up
b. Provide a purge system through the instrument to eliminate the effects of corrosive gases
c. Air-condition the optical system
d. Keep the optical windows free of particulates

15. How is transmittance related to opacity?

a. % opacity = % transmittance – Ringelmann number
b. Transmittance = (1 – % opacity) x 100
c. Transmittance/opacity = Ringelmann number
d. % opacity = 100% – % transmittance

16. The cascade impactor particle sizer can give representative particle size data if:

a. It is properly calibrated and operated
b. A cyclone is used to knock out large particle in the gas stream
c. Only if it is not at stack temperature when sampling
d. Agglomeration and fracturing of particles takes place in the device

17. For tangential cyclonic flow in a stack, the best way to determine the velocity is:

a. Orient the pitot tube until maximum reading is obtained. This is the true Δp.
b. Orient the pitot tube parallel to the sides of the stack and the Δp reading is the upward vector of the velocity.
c. Measure the impact pressure and the static pressure separately and by difference obtain the velocity head (Δp).
d. Install gas flow straightening vanes and sample in the usual manner.

18. "Isokinetic," in stack sampling, means:

a. The volumetric flow rate at the tip of the probe nozzle is equal to the volumetric flow rate at the metering device.
b. The velocity at the tip of the nozzle is equal to the velocity at the metering device.
c. The velocity at the tip of the nozzle is equal to the velocity of the approaching stack gas stream.
d. A term used by stack samplers to impress plant personnel.

19. Cascade impactor particle sizing devices are subject to errors produced when the sample gas flow rate through the device is too high. These errors are caused by:

a. Poor leak test procedures
b. Process fan fluctuations
c. Scouring and reentrainment of particles deposited on stage plates
d. Under isokinetic flow through the impactor

20. The Type S pitot tube is the most commonly used device for the EPA Method 5 sampling train gas sensor. It aids in the measurement of the stack gas velocity. The Type S pitot tube directly measures:

a. The gas velocity impact pressure and static pressure
b. Gas flow rate through the A and B legs of the tube
c. Stack gas viscosity
d. The difference between gas viscosity and gas density

21. Source sampling nozzles should be:

a. Tapered to $\leq 40^{o}$
b. Must not exceed 3/4" diameter
c. Calibrated regularly to the nearest (0.001 inch) 0.025 mm
d. Replaced at specific intervals

22. In the following equations

v_s = stack gas velocity

A_s = stack cross-sectional area

A_n = nozzle cross-sectional area

θ = sampling time (minutes)

V_m = standard volume metered at the dry gas meter

V_n = volume at stack conditions passing through the nozzle

The % isokinetic for a stack may be calculated using equation:

a. $\% \text{ isokinetic} = \frac{A_s}{A_n} \times 100$

b. $\% \text{ isokinetic} = \frac{V_n}{v_s \ A_s \theta}$

c. $\% \text{ isokinetic} = \frac{V_n}{\theta A_n \ v_s} \times 100$

d. $\% \text{ isokinetic} = \frac{V_m}{\theta A_s \ v_s} \times 100$

23. The New Source Performance Standards for a Fossil Fuel Fired Steam Generator define a particulate as:

a. Any solid or liquid in the stack gas
b. Any solid in the stack gas
c. Any solid or liquid other than uncombined water in the stack gas as measured by Method 5.
d. Any solid or liquid other than uncombined water as measured by Method 5 sampling train maintained at $\leq 400^{o}$F

24. An Orsat analyzer is commonly used to determine the composition of a combustion effluent where N_2, 0_2, CO, and $C0_2$ are the principal constituents of the gas stream. It directly measures:

a. 0_2, N_2, C0, and $C0_2$

b. C0, $C0_2$, 0_2

c. $C0_2$, 0_2, N_2

d. N_2, 0_2, C0

25. An Orsat analyzer yields results on a:

a. Wet basis because it essentially is a wet chemical analysis.
b. Wet basis because the effluent usually contains moisture.
c. Dry basis because the moisture condenses until the effluent is dry.
d. Dry basis because the vapor pressure of water remains the same.

26. The order in which we analyze the components is:

a. $C0_2$, 0_2, C0

b. 0_2, $C0_2$, C0, N_2

c. C0, 0_2, $C0_2$

d. N_2, 0_2, C0

27. The Type S pitot tube must be calibrated while assembled in the sampling configuration for which its use is intended. This is necessary because:

a. The Type S pitot tube is not an accepted standard for gas velocity measurements.
b. It may be Reynold's Number dependent
c. It is not manufactured according to an established National Standard
d. All the preceding reasons in conjunction with the dictates of good experimental procedure for preparation and use of any scientific measuring device.

28. Select the equation that best describes the calibration of a pitot tube using a known standard pitot tube.

a. $$C_p = \frac{Q_s / A_s}{K_p \sqrt{\frac{T_s \Delta p}{P_s \ M_s}}}$$

b. $$C_p = \frac{Q_s / A_s}{K_p \sqrt{\frac{P_s \Delta p}{T_s \ M_s}}}$$

c. $$C_p = C_{p(std)} \sqrt{\frac{\Delta p(std)}{\Delta p(test)}}$$

d. $$C_p = C_{p(std)} \sqrt{\frac{\Delta p(test)}{\Delta p(std)}}$$

A_s = stack cross-sectional area
C_p = pitot tube calibration coefficient
$C_{p(std)}$ = standard pitot-static tube calibration coefficient
K_p = dimensional constant
M_s = wet molecular weight of the gas
P_s = absolute pressure o the gas
Δp = pitot tube velocity pressure
$\Delta p(test)$ = test pitot tube velocity pressure
$\Delta p(std)$ = standard pitot static tube velocity pressure
Q_s = volumetric flow rate
T_s = absolute temperature of the gas

29. The D_{50} of a cascade impactor stage is defined as:

a. The particle diameter at which the stage is 50% efficient
b. The D_p of that stage
c. The particle diameter at which the stage is 50%
d. The D_{50} aerodynamic diameter of the particles on that stage

30. The photopic region is

a. The region of the electromagnetic spectrum covered by the spectral output of a tungsten filament.
b. The effective sensing area of the detector on a transmissometer.
c. The range of particle sizes which scatter visible light.
d. The visible region of the electromagnetic spectrum.

31. The moisture content of the stack gas enters into calculation of the wet molecular weight of the gas, in the expression:

a. $M_d = \Sigma M_x B_x$

b. $M_s = M_d (1-B_{ws}) + 18 (B_{ws})$

c. $M_s = M_d (1-B_{ws}) + 0.025$

d. $M_s = M_d (1-B_{ws}) + B_{ws}$

B_{ws} = mole fraction H_20 (% H_20)

M_s = weight molecular weight of the stack gas

32. What must you do if you encounter effluents other than $C0_2$, 0_2, C0, or air in order to determine the molecular weight?

a. Guess the molecular weight to be 29.
b. Use appropriate analytical procedures to determine the mole fraction of each constituent of the effluent gas.
c. Go ahead and use the Orsat anyway. The principle is "anything is better than nothing".
d. Use a Fyrite.

33. If you sample over-isokinetically, your particle concentration will be

a. Less than the true concentration
b. Greater than the true concentration
c. The true concentration
d. Greater than the true concentration only if large particles make up a significant percentage of the particle size distribution

34. A quick approximation of stack gas velocity in a duct can be made using the equation:

a. $v_s = 2.46 \sqrt{T_s \Delta p}$

b. $v_s = 85.48 \sqrt{(T_s \Delta p)}$

c. $v_s = K_p C_p \left[\frac{T_s P_m}{T_m P_s}\right]$

d. $v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s B_w}}$

35. The ideal gas law states that:

$$PV = \frac{m}{M} RT$$

Select the statement that is false.

a. The universal gas constant, R, is dimensionless.
b. The above relationship can be used to find the density of a gas at any conditions of P, T, and M.
c. Molecular weight is determined by knowing the composition of gas stream.
d. T must be in absolute units.

36. Why is the determination of moisture content of the effluent gas important in isokinetic sampling?

a. Because moisture tends to corrode the nozzle.
b. Because it enters as a variable in the isokinetic sampling equation and must be considered in setting the isokinetic flow rate.
c. It can dissolve particulates and yield low results.
d. It is not important in isokinetic sampling.

37. One of the important hydrodynamic principles used in isokinetic considerations, is

a. Large particles tend to move in their same initial direction.
b. Barriers to flow develop vortices.
c. Pressure is inversely related to volume.
d. A flowing gas stream will decrease the pressure in a tube normal to the flow direction.

38. Which one of the following relates pressure differential across a system to the flow rate of the gases in the system:

a. Stokes Law
b. Reynolds' Number
c. Bernoulli's Theorem
d. Avagadro's Number

39. Reference Method 4 in the Federal Register outlines the procedures for determination of the moisture content of a stack gas. Moisture content is best determined from the equation: (Note B_{wo} is the same as B_{ws})

a. $$B_{ws} = \frac{V_{wc}}{V_{wc} + V_m} + 0.02$$

b. $$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{sg(std)} + V_{m(std)}}$$

c. $$B_{ws} = \frac{1}{V_{wc} + V_m}$$

d. $$B_{ws} = 1\left[- \frac{V_{wc}}{V_m} \right]$$

40. The % isokinetic calculated at the end of a Method 5 test is a measure of:

a. The precision with which sampling rates were set based on test velocity and volumetric flow rate data
b. Experimental discrepancies
c. Experimental error
d. Accurate pollutant mass emissions

TRUE – FALSE

41. The static pressure of a duct is that pressure which would be indicated by a gage moving along with the gas stream in the duct.
42. The nomograph supplied with most commercial EPA trains is the most accurate method for setting isokinetic flow rate.
43. When any fuel is burned at 50% excess air, the flue gas will contain the same $\%0_2$, and $\% C0_2$.
44. An inclined manometer must always be leveled and properly zeroed if good Δp readings are expected.
45. Gas straightening vanes will assist in reducing gas turbulence within a duct.
46. The standard pitot tube has standard design criteria accepted by the National Bureau of Standards.
47. The analytical technique and properties of the pollutant and other constituents are of prime importance when designing sampling trains and experiments.
48. Sampling for the average pollutant concentration at the point of average velocity is common practice for isokinetic sampling.

49. The optical density measured across a stack can be correlated to mass emission concentration.

50. The relationship used to find the proper isokinetic sampling rate when the Δp is known, is:

$\Delta H = K \Delta p$.

ANSWER SHEET

Name ______________________________ Date ______________________________

1. a b c d
2. a b c d
3. a b c d
4. a b c d
5. a b c d
6. a b c d
7. a b c d
8. a b c d
9. a b c d
10. a b c d
11. a b c d
12. a b c d
13. a b c d
14. a b c d
15. a b c d
16. a b c d
17. a b c d
18. a b c d
19. a b c d
20. a b c d
21. a b c d
22. a b c d
23. a b c d
24. a b c d
25. a b c d
26. a b c d
27. a b c d
28. a b c d
29. a b c d
30. a b c d
31. a b c d
32. a b c d
33. a b c d
34. a b c d
35. a b c d
36. a b c d
37. a b c d
38. a b c d
39. a b c d
40. a b c d
41. T F
42. T F
43. T F
44. T F
45. T F
46. T F
47. T F
48. T F
49. T F
50. T F

ANSWER SHEET #450

Name KEY -- PRE-TEST

Date ____________________

1. a b c ●
2. a b ● d
3. a ● c d
4. a b ● d
5. ● b c d
6. ● b c d
7. a b ● d
8. a ● c d
9. a b ● d
10. a ● c d
11. a ● c d
12. a b c ●
13. a ● c d
14. a b c ●
15. a b c ●
16. ● b c d
17. a b c ●
18. a b ● d
19. a b ● d
20. ● b c d
21. a b ● d
22. a b ● d
23. a b ● d
24. a ● c d
25. a b c ●
26. ● b c d
27. a b c ●
28. a b ● d
29. ● b c d
30. a b c ●
31. a ● c d
32. a ● c d
33. ● b c d
34. ● b c d
35. ● b c d
36. a ● c d
37. ● b c d
38. a b ● d
39. a ● c d
40. ● b c d
41. ● F
42. T ●
43. T ●
44. ● F
45. ● F
46. ● F
47. ● F
48. T ●
49. ● F
50. ● F

SOURCE SAMPLING FOR PARTICULATE EMISSIONS
APTI COURSE NUMBER 450

POST TEST

DIRECTIONS: Circle the best answer (there is one and only one correct answer for each question). Mark answers both on your Exam Sheet and on the Answer Sheet. You will be asked to turn in only the Answer Sheet. The August 18, 1977 Federal Register and a scientific calculator may be used during this test. You will have 45 minutes to complete this test.

1. If the particulate concentration is measured as 0.1 grains per dry standard cubic foot (DSCF), and the stack gas flow rate is 70,000 DSCF per minute, what is the particulate emission rate in pounds per hour (7000 grains = 1 pound)?

   a. 60 pounds/hour
   b. 1 pound/hour
   c. 10 pounds/hour
   d. need more information

2. A Stack Tester needs an estimated stack gas velocity for pre-survey information. He is told that the stack gas is exiting from a combustion source and that the average stack gas temperature is $440^{o}F$. A velocity traverse with an "S" type pitot tube ($C_p = 0.85$) gave the average $\Delta p = 1.0$ in H_2O. Estimate the gas velocity in the duct.

   a. 69 ft./sec.
   b. 74 ft./sec.
   c. 60 ft./sec.
   d. 78 ft./sec.

3. A Type S pitot tube was calibrated against a standard pitot-static tube assigned a $C_p = 0.998$ by NBS. The Type S tube measured a $\Delta p = 0.500$. The standard tube measured a $\Delta p = 0.350$. What is the C_p of the Type S tube based on this data?

   a. $0.998\ (0.7)^2$
   b. $0.998/\sqrt{0.7}$
   c. $0.998\ \sqrt{0.7}$
   d. $0.998/(0.7)^2$

February 14, 1980

4. A Stack Test was performed at a wood fired boiler. The stack gas contained 10% H_2O and traveled up the stack at 30 ft./sec. The stack had a cross-sectional area of 20 $ft.^2$, average temperature of 335°F, and absolute pressure of 29.92 in. Hg. What was the volumetric flow rate in dry standard cubic feet per hour?

   a. 144,000
   b. 1,300,000
   c. 130,000
   d. 1,960,000

5. Method 1 presents guidelines for the selection of a sampling site and minimum number of sampling points for a particulate traverse for a stack diameter greater than 24 inches. The criterion for using 12 sampling points in the duct states that the sampling site is at least:

   a. 8 duct diameters downstream and 2 duct diameters upstream of a flow disturbance.
   b. 2 duct diameters downstream and 8 duct diameters upstream of a flow disturbance.
   c. 4 duct diameters downstream and 8 duct diameters upstream of a flow disturbance.
   d. 6 duct diameters downstream and 2 duct diameters upstream of a flow disturbance.

6. The Code of Federal Regulations outlines the procedures for Method 3. The method gives details on how to analyze the stack gas for its constituent components using the Orsat. Orsat analysis makes possible the calculation of:

   a. Mole fraction of CO_2, O_2, and CO, dry gas molecular weight and percent excess air in the duct
   b. Percent excess air, CO_2, and volumetric flow rate (dry)
   c. Percent CO_2, O_2, and CO, and moisture content
   d. Only the percent oxygen present in the dry gas

7. Method 1 guidelines suggest that all sampling points in a rectangular duct be located at the centroid of an equal area so that:

   a. There is a length to width ratio of 1:4
   b. There is a length to width ratio of 2:1
   c. Two and five are concentric equal areas
   d. There is a balanced matrix

8. Using Method 1 guidelines it is necessary to calculate an equivalent diameter (D_e) for rectangular stacks to be sampled. This is done using:

a. $D_e = \frac{(L)(W)}{(L)^2}$

b. $D_e = \frac{(L)(W)}{(W)^2}$

c. $D_e = \frac{2(L)(W)}{L+W}$

d. $D_e = \frac{4(L)(W)}{W+L}$

9. If fibers from a filter adhere to the gasket part of the filter assembly a proper procedure to follow would be to:

a Wash the gasket in an acetone/water rinse.

b. Retain the fibers on the gasket for the next run.

c. Scrape off the fibers into the filter recovery dish

d. Wipe the fibers off with a Kimwipe.

10. The mole fraction of H_2O in a stack gas as calculated by the Reference Method, is determined using the equation

a. $B_{ws} = \frac{V_{wc}}{V_{wc} + V_m} + 0.02$

b. $B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$

c. $B_{ws} = \frac{V_{wc}}{V_{wc} + V_m}$

d. $B_{ws} = \frac{1}{V_{wc} + V_m}$

11. The following statements give some of the advantages gained by using a **Type S** pitot tube. Which statement is not *always* true?

   a. The **Type S** pitot tube is easy to use in small sampling ports.
   b. The **Type S** pitot tube resists abusive environments and holds its calibration.
   c. The **Type S** pitot tube consistently calibrates to a known C_p value of 0.84, therefore, individual calibration is not necessary.
   d. The large gas sensing orifices of the **Type S** pitot tube help prevent clogging in heavily loaded particulate gas streams.

12. The standard pitot-static tube has small openings surrounding the tube for measuring:

   a. Standard pressure
   b. Static pressure
   c. Rotational gas velocity vector
   d. Parallel gas axis angle

13. The small opening surrounding the standard pitot-static tube may clog with particulate in a heavily loaded gas stream. For this reason the standard pitot-static tube should:

   a. Never be used for this type situation
   b. Used only to calibrate a **Type S** pitot tube
   c. Be a second choice to a well calibrated **Type S** tube in this situation
   d. Protected from clogging by stuffing glass wool into the small opening

14. The **Type S** pitot tube is the most commonly used device for the EPA Method 5 Sampling Train gas sensor. It aids in the measurement of the stack velocity. The **Type S** pitot tube directly measures:

   a. The difference between total pressure and static pressure
   b. Gas flow rate through the A and B legs of the tube
   c. Stack gas viscosity
   d. Difference between gas viscosity and gas density

15. The requirements concerning minimum distances for separation of the **Type S** pitot tube and any accessory on the sampling probe are established because:

   a. The **Type S** pitot tube has a slow response time when gas turbulence exists about the sensors.
   b. The **Type S** pitot tube has exhibited a sensitivity to gas turbulence that can effect its calibration coefficient.
   c. The **Type S** pitot tube must be isolated from the sampling nozzle to ensure that the volume at the nozzle equals the velocity of the approaching gas stream.
   d. Manufacture calibration guarantees are void if the pitot tube is too close to other train components.

16. In the isokinetic rate equation $\Delta H = K \Delta p$, K is:

   a. Always equal to 1.84
   b. Only a function of the stack temperature
   c. A function of many variables
   d. Independent of the C_p value

17. Isokinetic sampling is:

   a. Used only for gas sampling from stationary sources
   b. Is necessary when sampling for gases as well as for particulates to obtain the proper influx of pollutant
   c. The same as proportional sampling
   d. Is necessary to obtain a particulate sample having the same size distribution as that occurring in the stack

18. What is the purpose of the Method 5 nomograph?

   a. It is a type of slide rule used to determine the Δp for the chosen sampling train. size.
   b. It is a type of slide rule used to correct the nozzle velocity to standard conditions.
   c. It is a type of slide rule used to determine a ΔH from the observed Δp.
   d. It is a type of slide rule used to determine a Δp from the observed ΔH.

19. In the expression $\Delta H = K \Delta p$, K represents the reduction of several variables into a constant term that may be calculated for the existing conditions at the source. Which of the following variables is assumed to be zero in the reduction of terms to K?

   a. $\Delta H_{@} = 0$
   b. $B_{wm} = 0$
   c. $B_{ws} = 0$
   d. $(1-B_{ws}) = 0$

20. A Source Test was performed at an isokinetic rate of 86%. The emissions calculated from this test are biased:

   a. By large particulates and a higher emission rate than true
   b. By large particulates and a lower emission rate than true
   c. Small particulates and a higher emission rate than true
   d. Small particulates and a lower emission rate than true

21. A transmissometer measures the opacity of an effluent stream using light with wave lengths between 500-600 nm. These wave lengths are chosen for which of the following reasons?

   a. These wave lengths are specific to fly ash particles
   b. Transmissometer opacity readings in this area of the electromagnetic spectrum are free from H_2O and CO_2
   c. Present technology does not allow economical construction of instruments employing other wave lengths
   d. Combustion sources emit light in this region of the spectrum

22. The percent isokinetic should be 100%, and if it is:

   a. It ensures sampling accuracy.
   b. It means only that, based on the volumetric and velocity data, the proper sampling rates were used.
   c. It means that the source is in compliance with regulations.
   d. It means that only the pollutant mass rate will be accurate.

23. In the clean-up procedures of an EPA particulate train, acetone is used to wash all internal surfaces of:

   a. Nozzle, probe, and front half of filter holder
   b. Answer "a," except the probe is rinsed only if the liner is glass
   c. Probe and filter holder only
   d. Acetone is not used because it is highly volatile

24. A sampling team performed reference method 5 particulate test at a municipal incinerator. Test results showed an emission rate of 0.01 lb./dscf with 8% CO_2 in the stack gas. What is the emission rate connected to 12% CO_2?

   a. 0.010 lb./dscf
   b. 0.015 lb./dscf
   c. 0.020 lb./dscf
   d. 0.025 lb./dscf

25. Error analysis of the Method 5 sampling system suggests that the greatest errors occur in determination of:

   a. Stack gas velocity and dry molecular weight
   b. Stack gas velocity and sampling site selection
   c. Stack gas velocity and wet molecular weight
   d. Stack gas velocity and moisture content

26. If entrained water is observed in the stack, which of the following methods would give the best estimate for B_{ws}?

   a. Just use the saturated moisture value at the stack temperature
   b. Use the wet bulb-dry bulb method
   c. Use Method 4
   d. Just use the saturated moisture value at the ambient temperature

27. The moisture content of the stack gas enters into the calculation of the wet molecular weight of the gas, in the expression:

   a. $M_d = \Sigma M_x B_x$
   b. $M_s = M_d(1-B_{ws}) + 18(B_{ws})$
   c. $M_s = M_d(1-B_{ws}) + 0.025$
   d. $M_s = M_d(1-B_{ws}) + B_{ws}$

28. For tangential cyclonic flow in a stack, the best way to determine the velocity is:

   a. Orient the pitot tube until maximum reading is obtained. This is the true Δp
   b. Orient the pitot tube parallel to the sides of the stack. The Δp reading is the upward vector of the velocity
   c. Measure the impact pressure and the static pressure separately and by difference obtain the velocity head (Δp)
   d. Install gas flow straightening vanes and sample in the usual manner

29. Best Tester sampling team had just completed a Method 5 test at a cost of $2000 to the source. The value obtained for the emissions, E, in lbs/10^6 Btu, was below the standard, indicating that the source was in compliance. The test itself, however, was only 80% isokinetic. This test data:

- a. Would be rejected by EPA since it is not within ± 10% of 100% isokinetic.
- b. Could be easily corrected to give the value of E at 100% isokinetic conditions.
- c. Could be accepted by EPA since the value of E would be even lower at 100% isokinetic conditions.
- d. Could be accepted by EPA since the value of E would be even higher at 100% isokinetic conditions.

30. Correcting pollutant concentrations to 12% CO_2 is applicable to:

- a. All processes
- b. Incineration processes and other combustion sources
- c. Sources in operation prior to April 1, 1970
- d. Sources covered by State Implementation Plans

31. The ideal gas law states that:

$$PV = \frac{m}{M} RT$$

Select the statement that is false.

- a. The universal gas constant, R, is dimensionless.
- b. The above relationship can be used to find the density of a gas at any conditions of P, T, and M.
- c. Molecular weight is determined by knowing the composition of gas stream.
- d. T must be in absolute units.

32. The D_{50} of a cascade impactor stage is defined as:

- a. The average aerodynamic diameter of the particles on that stage
- b. The physical diameter of the particles on that stage
- c. The particle diameter at which the stage is 50% efficient
- d. Calibration coefficient of that stage

33. Cascade Impactor particle sizing devices are subject to errors produced when the sample gas flow rate through the device is too high. These errors are caused by:

a. Anisokinetic flow through the impactor
b. Over isokinetic flow through the impactor
c. Under isokinetic flow through the impactor
d. Scouring and reentrainment of particles deposited on stage plates

34. The maximum total angle of radiation that can be projected by the lamp assembly of the transmissometer is known as:

a. The angle of trajectory
b. The angle of declination
c. The light scattering angle
d. The angle of projection

35. How is transmittance related to opacity?

a. transmittance = $\log_{10} \frac{1}{(1\text{-opacity})}$
b. transmittance/opacity = – naql
c. % opacity = 100% – % transmittance
d. % opacity = % transmittance – naql

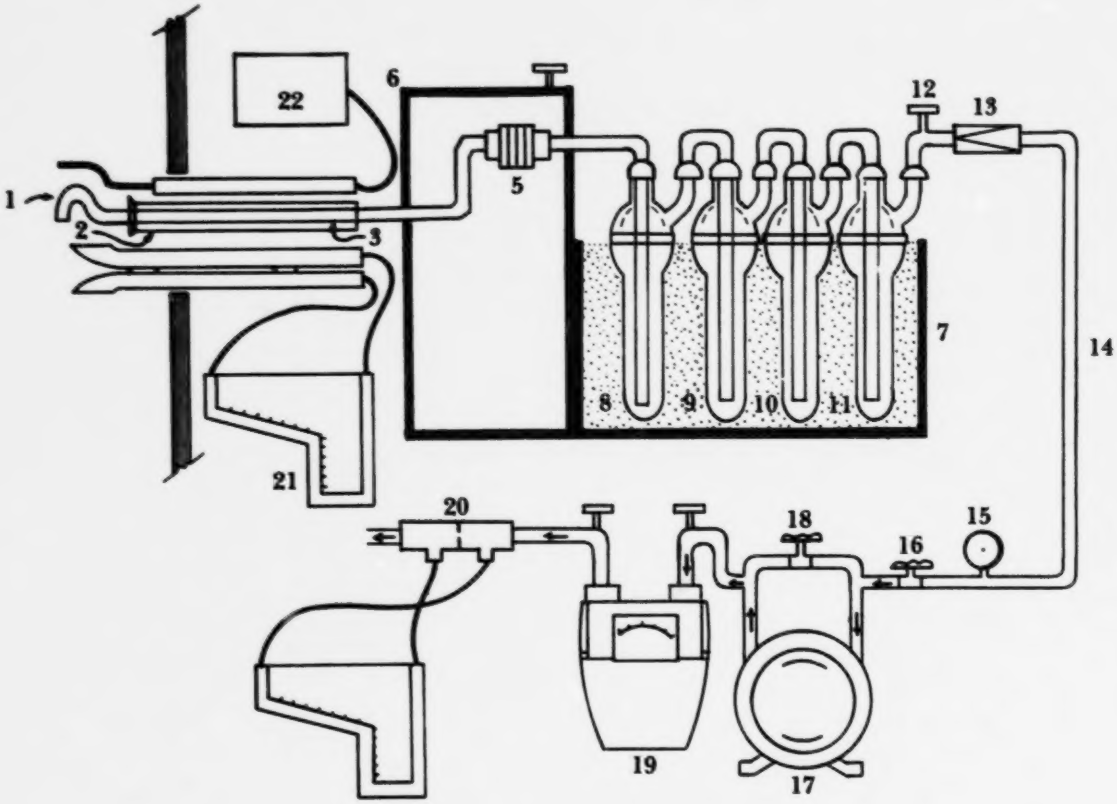
36. A transmissometer will provide information on mass emissions from a pollutant source for a given time period if:

a. The neutral density filters are calibrated to 3% and the particle characteristics do not change.
b. A reference light source is used and the particle characteristics do not change.
c. The manufacturer supplies a calibration chart.
d. The optical density can be correlated to grain loading and the particle characteristics remain unchanged.

37. If a post-leak check of a Method 5 train gives a value of .032 cfm, the test should be:

a. Rejected without question.
b. Accepted without question.
c. Accepted, if V_m is corrected, using the leak rate value
d. Accepted, if V_m is modified by averaging the pre-test and post-test leak rates.

The following questions are related to the diagram of the Method 5 Sampling Train. Questions vary in complexity from simple identification of equipment to others that test understanding and comprehension of equipment use.



38. When performing an EPA Method 5 test, in order to draw a sample through the sampling train at a controlled rate, the by-pass valve is:

   a. Turned all the way off
   b. Turned clockwise from a fully open position
   c. Turned counter-clockwise from an off position
   d. Turned to a fully open position

39. What is the function of the orifice meter in a Method 5 test?

a. It is used to eliminate correcting the sample volume to standard conditions
b. It is used to determine the value of K of the isokinetic rate equation during the test
c. It is used to determine the flow rate of the gas through the sampling train
d. It is used to determine the flow rate of the gas in the stack

40. In the EPA Method 5 Sampling Train, what are each of the impingers filled with and what is the correct order?

a. 1 – 100cc H_20, 2 – Dry, 3 – 100cc H_20, 4 – Silica Gel (100g)
b. 1 – 100cc H_20, 2 – 200cc H_20, 3 – Dry, 4 – Silica Gel (200g)
c. 1 – 100cc H_20, 2 – 100cc H_20, 3 – Dry, 4 – Silica Gel (200g)
d. 1 – 200cc H_20, 2 – 200cc H_20, 3 – Dry, 4 – Silica Gel (100g)

41. All leak checks for the sample train should be conducted:

a. From the nozzle inlet with all train components at operating temperature
b. From the filter inlet at room temperature
c. From the probe inlet at ambient temperature
d. From the nozzle inlet at ambient temperature

42. The post-test leak check at the highest vacuum recorded during the stack test is:

a An unnecessary and useless procedure because it is not required by present regulations
b. A possible source of error creating particulate penetration through the glass mat filter
c. Required in the August 18, 1977 Federal Register revisions to Method 5
d. The work of a novice tester unaware of the possible problems

43. The August 18, 1977 Federal Register gives guidelines on the type of sampling probe liner that may be used in the Method 5 sampling system. It recommends that probe liners be:

a. Borosilicate glass
b. Borosilicate glass or stainless steel
c. Quartz glass or stainless steel
d. Borosilicate or quartz glass; stainless steel with the approval of the administrator

44. The Federal Register guidelines for Method 5 suggest a pre-test leak check of the sampling train. The test recommendations are:

a. A leak check of the entire system at operating temperature and a vacuum gage reading of 15 in. Hg
b. A leak check of the entire system at a vacuum gage reading of 14 in. Hg
c. A leak check at the filter inlet at a vacuum gage reading of 14 in. Hg and maximum leak rate of 0.02 cfm
d. A leak check at the filter inlet at a vacuum gage reading of 15 in. Hg and maximum leak rate of 0.25 cfm

45. The F-Factor is:

a. Used to determine the concentration of the stack gas.
b. Permitted by the Federal Register to convert emissions data for FFFSG into the units lb/10^6 Btu.
c. Used to calculate the stack gas volumetric flow rate
d. Used to determine the (pmr) pollutant mass rate.

46. The EPA Method 5 Sampling procedure specifies that the out-of-stack filter temperature (unless stated otherwise in the subparts) be maintained at

a. $\leq$ 250°F
b. $\geq$ 250°F
c. No greater than 248°F ± 25°F
d. 250°F

47. Maintaining the filter at this temperature is:

a. Part of the definition of "particulate" as the method is written
b. Necessary to prevent sulfate formation on the glass mat
c. The best temperature to assure a leak-tight filter holder
d. Easier than setting it at any other temperature

48. The desired flow rate through the Method 5 Sampling Train is 0.75 cfm dry air at 68°F and 29.92 in. Hg. These conditions are designated by a single term $\Delta H_@$. Solving the orifice meter flow rate equation for a $\Delta H_@$ that meets the stated conditions we find:

a. $\Delta H_@ = \dfrac{Q_m^{\ 2}}{K_m^{\ 2}}$

b. $\Delta H_@ = \dfrac{1}{K_m^{\ 2}}$

c. $\Delta H_@ = \dfrac{0.9244}{K_m^{\ 2}}$

d. $\Delta H_@ = \dfrac{Q_m}{K_m} \left[\dfrac{P_m}{T_m}\right]^2$

ANSWER SHEET #450

Name KEY -- POST TEST

Date ________________

3 pts each

1. ● b c d
2. a ● c d
3. a b ● d
4. a ● c d

all others

2 pts

5. ● b c d
6. ● b c d
7. a b c ●
8. a b ● d
9. a b ● d
10. a ● c d
11. a b ● d
12. a ● c d
13. a b ● d
14. ● b c d
15. a ● c d
16. a b ● d
17. a b c ●
18. ● b ● d
19. a ● c d
20. ● b c d
21. a ● c d
22. a ● c d
23. ● b c d
24. a ● c d
25. a b c ●
26. ● b c d
27. a ● c d
28. a b c ●
29. a b ● d
30. a ● c d
31. ● b c d
32. a b ● d
33. a b c ●
34. a b c ●
35. a b ● d
36. a b c ●
37. a b ● d
38. a ● c d
39. a b ● d
40. a b ● d
41. ● b c d
42. a b ● d
43. a b c ●
44. ● b c d
45. a ● c d
46. a b ● d
47. ● b c d
48. a b ● d

ANSWERS TO ADDITIONAL PROBLEMS
Given as Homework
(See Workbook pages 175-181)

PROBLEM #1

Stack diameter: 16"

Upstream to nearest disturbance: 54"

Downstream to nearest disturbance: 125"

Diameter: Upstream: $\frac{54''}{16''}$ = 3.37 eq. Dia = 8 pts

Diameter: Downstream: $\frac{125''}{16''}$ = 7.81 eq. Dia = 10 pts

From Figure #1-1 of Federal Register, calculate 10 traverse pts.

∴ choose 12 traverse pts. Because the number has to be a multiple of 4.

	Sample Point Number		Circular Stack % Diameter	Distance from Sample Port Opening in.
1st Traverse Diameter	1.	1A	0.044	0.70"
	2.	2A	0.146	2.33"
	3.	3A	0.296	4.73"
	4.	4A	0.704	11.26"
	5.	5A	0.854	13.66"
	6.	6A	0.956	15.29"
2nd Traverse Diameter	7.	1B	0.044	0.70"
	8.	2B	0.146	2.33"
	9.	3B	0.296	4.73"
	10.	4B	0.704	11.26"
	11.	5B	0.854	13.66"
	12.	6B	0.956	15.29"

PROBLEM #2

$$v_s = K_p \; C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$$

$K_p = 85.49$

$C_p = 0.845$

$T_s = 303 + 460 = 763\ ^{o}R$

$\Delta p = 0.15$

$P_s = 30.3'' \text{ Hg}$

$$M_d = 0.44\ (\%CO_2) + 0.32\ (\%O_2) + 0.28\ (\%N_2 + \%\ CO)$$
$$M_d = 0.44\ (14.2) + 0.32\ (5.0) + 0.28\ (80.8)$$
$$M_d = 6.248 + 1.6 + 22.62$$
$$M_d = 30.47$$

$$M_s = M_d\ (1-B_{ws}) + 18\ B_{ws}$$
$$M_s = (30.47)(1-0.07) + 18(0.07)$$
$$= 28.34 + 1.26$$
$$= 29.59$$

$$v_s = (85.49)(0.845) \sqrt{\frac{(763)(0.15)}{(30.3)(29.59)}}$$
$$= 72.24 \sqrt{\frac{114.45}{896.79}}$$
$$= 72.24 \sqrt{0.128}$$
$$= \boxed{25.81 \text{ ft/sec.}}$$

$$Q_s = 3600\ (1-B_{ws})\ v_s\ A \left(\frac{T_{std}}{T_{s(avg)}}\right) \left(\frac{P_s}{P_{std}}\right)$$
$$= 3600\ (1-0.07)(25.81)\ (A) \left(\frac{528}{763}\right)\left(\frac{30.3}{29.92}\right)$$

$$\text{Diameter} = \frac{16''}{2} = 8''\ \text{radius}$$

$$\text{Area} = \pi\ r^2$$
$$= (3.14)(8)^2 = \frac{201\ \text{sq. in.}}{144\ \text{sq. in./sq. ft}} = 1.40\ \text{ft}^2$$

$$= 3600\ (1-0.07)(25.81)\ (1.40)\left(\frac{528}{763}\right)\left(\frac{30.3}{29.92}\right)$$
$$= 8.48 \times 10^4\ \text{ft}^3/\text{hr.}$$

$$Q_A = (v_s)(A) = (25.65\ \text{ft/sec})(1.40\ \text{ft}^2)$$
$$= 35.91\ \text{ft}^3/\text{sec.}$$
$$(35.91\ \text{ft}^3/\text{sec})(3600\ \text{sec/hr.}) = \boxed{1.29 \times 10^5\ \text{ft}^3/\text{hr.}}$$

PROBLEM #3

$$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$$

$K_p = 85.49$

$C_p = 0.842$

$T_s = 300 + 460 = 760\ ^oR$

$\Delta p = 2.5''\ H_2O$

$P_s = 30.1 + \left(\frac{-15.0}{13.6}\right)$

$= 28.99$

$M_d = 0.44\ (\%CO_2) + 0.32\ (\%\ O_2) + 0.28\ (\%\ N_2 + \%\ CO)$

$\%\ CO_2 = 17$

$\%\ O_2 = 2$

$\%\ N = 100 - 19 = 81$

$= 0.44\ (17) + 0.32\ (2) + 0.28(81)$

$= 7.48 + .64 + 22.68$

$= 30.8$

$M_s = M_d\ (1-B_{ws}) + 18\ (B_{ws})$

$= (30.8)\ (1-0.12) + 18\ (.12)$

$= 27.10 + 2.16$

$= 29.26$

$$v_s = (85.49)(0.842)\sqrt{\frac{(760)(2.5)}{(28.99)(29.26)}}$$

$$= (71.9826)\sqrt{\frac{1900}{848.36}}$$

$$= (71.9826)(1.4965) = \boxed{107.72\ \text{ft/sec.}}$$

PROBLEM #4

H_2O collected in impingers: 75 ml

H_2O collected in the silica gel: 25 g

Volume = 40.20 ft^3

P_m = 30.0" Hg

T_m = 100 °F + 460 = 560 °R

(a) $$V_{m(std)} = K_3 Y \frac{V_m P_m}{T_m} = (17.64)(1)\ \frac{(40.20)(30.0\text{" Hg})}{560}$$
$$= 37.991 \text{ SCF}$$

(b) $$V_{wc(std)} = K_1\ (V_f - V_i)$$
$$= (0.04707\ ft^3/ml)\ (75 ml)$$
$$= 3.53\ ft^3$$

(c) $$V_{wsg(std)} = K_2\ (W_f - W_i)$$
$$= (0.04715\ \ ft^3/g)(25\ g)$$
$$= 1.18\ ft^3$$

(d) $$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

$$= \frac{3.53 + 1.18}{3.53 + 1.18 + 37.99} = \frac{4.71}{42.70} = .1103$$

.1103 x 100% = 11.03%

PROBLEM #5

(a) $$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{(std)}}{\Delta p_{(s)}}}$$

$$= 0.99 \sqrt{\frac{0.31}{0.42}} = 0.851$$

(b) $$M_d = 0.44(\%CO_2) + 0.32(\%O_2) + 0.28\ (\%N + \%\ CO)$$

$$= 0.44\ (13) + 0.32(6) + 0.28\ (80)$$

$$= 5.72 + 1.92 + 22.4$$

$$= \boxed{30.04\ \text{lb/lb-mole}}$$

(c) $$M_s = (1-B_{ws})\ M_d + 18\ B_{ws}$$

$$= (1-.1)\ 30.04 + 18(.10)$$

$$= 27.036 + 1.8$$

$$\boxed{28.84\ \text{lb/lb-mole}}$$

(d) $$\bar{v}_s = K_p C_p \sqrt{\frac{T_{s(avg)}}{P_s M_s}} \sqrt{\Delta p}$$

$$= (85.49)(0.851) \sqrt{\frac{810}{(29.00)(28.84)}} \quad \sqrt{0.59}$$

$$= (72.75)\left(\sqrt{\frac{810}{836.36}}\right) \left(\sqrt{0.59}\right)$$

$$= (72.75)\quad (0.984)(0.768)$$

$$= \boxed{54.98\ \text{ft/sec}}$$

(e) $$Q_s = 3600\ (1-B_{ws})\ v_s\ A \left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

$$= 3600\ (.9)(54.98)(1200)\ \left(\frac{528}{810}\right)\left(\frac{29.00}{29.92}\right)$$

$$= 3600\ (.9)(54.98)(1200)(.652)(0.969)$$

$$= \boxed{1.35 \times 10^8\ \text{DSCFH}}$$

PROBLEM #6

(a) $V_{m(std)} = K_1 Y V_m \dfrac{P_{Bar} + \dfrac{\Delta H}{13.6}}{T_m} = (17.64)(1)(50) \dfrac{(29.5) + \dfrac{1.5}{13.6}}{560}$

$= 46.64$ DSCF

$V_{ws} = K_1 (V_f - V_i)$

$= 0.04707\ (100) = 4.707$ SCF

(b) $B_{ws} = \dfrac{4.707}{4.707 + 46.64} = \dfrac{4.707}{51.343} = .0919$

$.0919 \times 100\% = 9.19\%$

(c) $C_s = \dfrac{100 \text{ mg}}{46.46 \text{ ft}^3} = \dfrac{.100}{46.46 \text{ ft}^3} = 0.00215 \text{ g/ft}^3$

$(0.0215 \text{ g/ft}^3)(15.43) = 0.033$ gr/DSCF

(d) $\%I = 100 \times \dfrac{T_s V_{m(std)}\ P_{std}}{T_{std} \overline{v}_s \overline{P}_s\ \theta \text{ min. } (60 \text{ sec/min})\ A_n (1 - B_{ws})}$

$= 100 \ \dfrac{(760)(46.64)(29.92)}{(528)(48)(29)(60)(60)(.00034)(1-.0919)}$

$= \dfrac{1.06 \times 10^8}{8.17 \times 10^5} = 0.1297 \times 10^3$

$= 129.7\ \%I$

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: WELCOME AND REGISTRATION

COURSE: 450 - Lecture 1
LESSON TIME: 30 minutes
PREPARED BY: Giuseppe J. Aldina
DATE: 10/2/78

Lesson Goal:

Allow students to introduce themselves to the class; determine the actual level of job experience in the class - the number of stack tests in which each student has participated.

Lesson Objectives:

Each student should know:

1. The following information:
    a. Organization presenting the course
    b. Organization providing the funds for the course (e.g. - EPA Manpower and Technical Information Branch)
    c. Organization providing the course materials (e.g. Northrop Services, Inc. under contract to EPA)

2. The name of all instructors and their affiliation

3. The name and employer of each student in the class

4. Phone number where a student may receive messages

5. Requirements for passing the course
    a. Completed registration card
    b. Pre-test
    c. 95% attendance - minimum
    d. All laboratory work completed and turned in
    e. Post-test - 70% minimum passing grad
    f. Critique

6. Teaching method in the course - problem solving using the basics learned in these lectures.

7. All class materials
    a. Workbook
    b. Manual

    - c. Quality assurance document
    - d. Agenda
    - e. Selected handouts
    - f. Note paper
    - g. Federal Registers; 8/18/77; 2/23/78
    - h. Registration card
    - i. APTI chronological course schedule
    - j. EPA Traineeship Program Brochure

7. Location of
    - a. Restrooms
    - b. Refreshments

8. Address and phone number (919-541-2766) of EPA - APTI MD-20, Research Triangle Park, N. C. 27711 as the place to contact concerning course materials and the EPA air pollution training program.

Support Materials:

1. Student materials package
2. Blackboard and chalk

CONTENT OUTLINE

Course: 450 Lecture 1
Lecture Title: WELCOME AND REGISTRATION

Page 1 *of* 3

NOTES

I. Introduce instructors

  A. Names and affiliation

  B. Experience

  C. Areas of expertise

II. Explain relationship between the organization presenting the course and EPA-APTI-MTIB

III. Logistics of the course location

  A. Message phone number

  B. Restrooms

  C. Refreshments and restaurants

IV. Introductions - have each student stand

  A. Let student give name and employer

  B. Have the student describe stack test experience

    1. Number of tests or years in stack testing

    2. Level of participation

      a. Observer

      b. Engineer in the field

      c. Report writing

  C. Have the student describe what he hopes to get from the course

V. Description of teaching methods

  A. Training

    1. Course directed at training students to perform a specific skill

    2. Methods used in the course will be explicit not implicit

B. Instructors

1. Will be there to help student become trained

2. Will add their experience and expertise to the training

3. Encourage questions

C. Approach

1. Teach the basic math and sampling techniques

2. Solve new problems by applying these fundamentals

VI. Course requirements

A. Completed registration card

B. Pre-test

C. 95% attendance - minimum

D. All laboratory work completed and turned in

E. Post-test - 70% minimum passing grade

F. Course critique completed and turned in

VII. Materials - have students check that they have

A. Manual

B. Workbook

C. Agenda

D. Quality assurance document

E. Federal Registers; 8/18/77; 2/23/78

F. Note paper

G. Registration card

H. Selected handouts

I. APTI Chronological Course Schedule

J. EPA Fellowship Program Brochure

CONTENT OUTLINE

Course: 450 Lecture 1
Lecture Title: WELCOME AND REGISTRATION

Page 3 of 3

NOTES

VIII. Pre-test and registration

- A. Explain that the pre-test
  - 1. Tests what they know as they enter the course
  - 2. Does not count in the final course grade
  - 3. Will be correlated to post-test grades to measure actual learning in the course
  - 4. Students should not guess at answers
- B. Registration card - completely filled out
- C. Begin the pre-test and tell students to take a break after the test
- D. Collect all tests and registration cards - grade tests promptly and report low, high, and average grades

LESSON PLAN

AIR POLLUTION
TRAINING INSTITUTE

TOPIC: INTRODUCTION TO SOURCE SAMPLING

COURSE: 450 - Lecture 2
LESSON TIME: 1 hour - 15 minutes
PREPARED BY: J. A. Jahnke
DATE: 9/20/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

2

Lesson Goal:

To introduce the student to the symbols and common source sampling terms to be used in the course. To introduce the student to the basic EPA Method 5 Train and the basic concepts of gas physics needed for the comprehension of the course material.

Lesson Objectives:

The student will be able to:

1. Locate the goals and objectives of the course in the course manual.
2. Define the symbols and common source sampling terms used in the course.
3. Recognize the basic features of the EPA Method 5 sampling train.
4. Write the expressions for pollutant mass rate and emission rate, using symbols for stack gas concentration, stack gas volumetric flowrate, and heat input rate.
5. Recognize the pitot tube equation on sight and understand the relative importance of the parameters in the equation.
6. Write the ideal gas law equation and be able to describe the effects of changing pressure and temperature on a gas volume.
7. Recognize the form of an ideal gas law correction equation.
8. Recognize the importance of Bernoulli's principle, gas viscosity and gas Reynold's number in source sampling.

Student Prerequisite Skills:

Basic mathematics

Level of Instruction:

College Undergraduate Science

Preceding page blank

Intended Student Professional Background:

High school math and high school or college general science.

Support Materials and Equipment:

1. Course workbook
2. Course manual
3. Projector

Special Instructions:

This lecture lays the foundation for the rest of the course. Stress on the ideal gas law equation is important. It has been found necessary to review the Method 5 Sampling Train before Lesson 2, since some students may not be familiar with the terminology in the lecture. The detailed explanation of the sampling train in Lesson 3 supplements this earlier introduction.

References:

None.

CONTENT OUTLINE

Course: 450 Lecture 2
Lecture Title: INTRODUCTION TO SOURCE SAMPLING

Page 1 **of** 5

NOTES

The purpose of this lecture is to introduce the students to the EPA Method 5 train, source sampling terminology, the reasons for obtaining Method 5 data, and to review the ideal gas law equation.	
I. Review of course objectives	students to turn to page 3 workbook
A. Symbols and terms - objectives	
B. Calculations	
C. Equipment familiarity	
D. Isokinetic sampling	
E. Doing the source test	
F. New methods	
II. Methods of source sampling	
A. Methods of monitoring source emissions	slide L2-1a-f
1. Manual	Turn to page 14 of workbook
2. Extractive-continuous	
3. In-situ-continuous	
4. Remote sensing	
5. Long path	
6. Visible emissions observations	
III. B. The manual method for particulates - EPA methods	L2-2
1. Review Method 5 Train - show flow	Diagram on page 18
2. Define each of terms used - pitot tube, orifice meter, etc.	
3. Define isokinetic sampling - iso - same as, kinetic - pertaining to motion. State that purpose of M5 train is that $v_n = v_s$	
4. Show slides of train	L2-3 L2-4 L2-5 L2-6
Point out significant features - orifice meter, fine control knob, filter holder	

III. Nomenclature

A. Symbols and subscripts

L2-7
L2-8

1. Review symbols and subscripts - defining important terms such as Δp, ΔH, $\Delta H_@$, etc.

Nomenclature on pages 10-13 of workbook

2. Stress that they are using English units since equipment is designed that way - not a course in metric conversion

3. Define standard temperature = $68^\circ F$ and pressure = 29.92 "Hg - define absolute T in $^\circ R$ and absolute pressure

B. Pollutant mass rate and emission rate

1. Reason for doing Method 5 test - to obtain concentration, pollutant mass rate, emission rate

a) Concentration c_s

Write on chalkboard or OH projector

$$c_s = \frac{\text{quantity of pollutant (mass)}}{\text{quantity of effluent gas (volume)}}$$

units: grains/ft^3 lbs/ft^3 $\frac{\text{grams}}{M^3}$

note: 7000 grains = 1 lb

b) Stack gas volumetric flow rate $\overline{Q}_s$

Write on chalkboard

$$\overline{Q}_s = \frac{\text{quantity of effluent gas passing up stack (volume)}}{\text{time}}$$

$\frac{ft^3}{hr}$, etc.

$$Q_s = \underbrace{A_s}_{\text{area of stack}} \underbrace{v_s}_{\text{stack gas velocity}} = ft^2 \times \frac{ft}{hr} = \frac{ft^3}{hr}$$

c) Pollutant mass rate $\overline{pmr_s}$

$$\overline{pmr_s} = \frac{\text{quantity of pollutant (mass) passing up stack}}{\text{time}}$$

$$\frac{\text{lbs}}{\text{hr}} , \quad \frac{\text{grains}}{\text{hr}} , \quad \frac{\text{grams}}{\text{hr}}$$

d) Relationship of the three units

$$\overline{pmr_s} = \overline{c_s}\, Q_s$$

$$= \underset{\overset{\uparrow}{\frac{m}{V}}}{\frac{\text{lbs}}{\cancel{\text{ft}^3}}} \; \underset{\overset{\nwarrow}{A_s v_s}}{\frac{\cancel{\text{ft}^3}}{\text{hr}}} = \frac{\text{lbs}}{\text{hr}}$$

Stress units and unit cancellation

e) Emission rate - NSPS units are given in terms of the weight of emissions/10^6 Btu heat input

$$E = \frac{\overline{pmr_s}}{Q_H} = \frac{\overline{c_s}\ \overline{Q_s}}{Q_H}$$

$$Q_H = \text{heat input rate} = \frac{10^6 \text{Btu}}{\text{Hr}}$$

See course manual Page 9-5

$$E = \frac{\frac{\text{lbs}}{\cancel{\text{ft}^3}} \frac{\cancel{\text{ft}^3}}{\cancel{\text{hr}}}}{\frac{10^6 \text{ Btu}}{\cancel{\text{hr}}}} = \frac{\text{lbs}}{10^6 \text{ Btu}}$$

f) Review of pollutant mass rate

L2-9

1. Refer to slide - pointing out the large number of variables in the test

Page 14 of workbook

2. Point out necessity for isokinetic sampling

L2-10

3. Point out pitot tube equation - make no attempt to derive - point out variables

L2-11

[Memorize]

Comes from Bernoulli's principle

$$v_s = \underset{\text{EPA M2}}{K_p} C_p \sqrt{\frac{\overset{M2}{T_s}\ \overset{M2}{\Delta p}}{\underset{M2}{P_s}\ \underset{M3\ M4}{M_s}}}$$

Will do these in the laboratory

4. Re-emphasize importance of emission rate calculation - This is the END RESULT

L2-12

$$E = \frac{c_s \bar{Q}_s}{\bar{Q}_H}$$

IV. Gas physics - review of concepts

By now, students are somewhat tired and almost saturated - but this is Berlitz and the instructor must press on

A. Ideal gas law

1. Important in course

$$PV = \frac{m}{M} RT \qquad PV = nRT$$

review terms $R = 21.83 \frac{(\text{in. Hg})(\text{ft}^3)}{\text{lb-mole } ^\circ\text{R}}$

Write on board

review mole concept

mole = molecular weight in grams or pounds

Few students understand the concept of the mole - stress its importance in chemistry

2. A trick

$$p = \frac{m}{V} \frac{RT}{M} = c \frac{RT}{M}$$

c = concentration

Ask students what c is

B. Correcting pressure or volume to standard conditions - very important

1. Do this derivation

$$V_{\substack{corr\\to\\std}} = nR\,\frac{T_{std}}{P_{std}} \qquad V_{stack} = nR\,\frac{T_s}{P_s}$$

for the same number of moles (molecules) of gas, what volume would these molecules occupy at standard conditions, rather than stack conditions?

L2-13

$$\frac{V_{corr}}{V_s} = \frac{\dfrac{nRT_{std}}{P_{std}}}{\dfrac{nR\,T_s}{P_s}} = \frac{P_s\,T_{std}}{P_{std}\,T_s}$$

$$V_{corr} = V_s\,\frac{P_s\,T_{std}}{P_{std}\,T_s}$$

Very important to understand this - essential for understanding operation of Method 5 train

C. Other terminology of gas physics

L2-14

1. Bernoulli's principle

$$1/2\ m\Delta v^2 + mg\ \Delta h + V\Delta p = 0$$

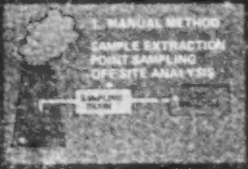
Pitot tube equation derived from this expression

2. Viscosity - η

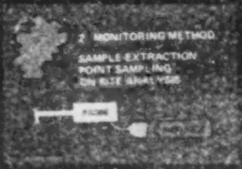
3. Reynolds' number - N_{Re}

Refer students to Course Manual - Chapter 2 page 2-10
They are now too saturated to absorb any more mathematics - Take a break-next lecture to be show and tell - easing off
Note: Students who have had no previous experience in source sampling will forget what $\overline{pmr}_s$ or E mean, by Tuesday afternoon-Review the definitions on occasion throughout the course.

12/79 450 LESSON 2 1


1. MANUAL METHOD
SAMPLE EXTRACTION
POINT SAMPLING
OFF SITE ANALYSIS
SAMPLING TRAIN

1a


2. MONITORING METHOD
SAMPLE EXTRACTION
POINT SAMPLING
ON SITE ANALYSIS

1b

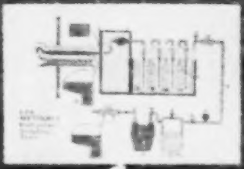
3. IN-SITU MONITORING
NO SAMPLE EXTRACTION
POINT OR INTEGRATED

1c

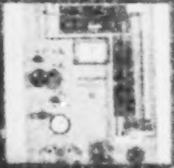
1d

1e

1f



2

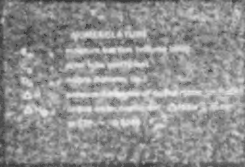


3

4

5

6

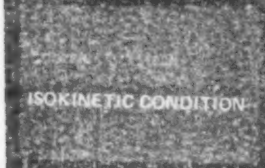


7

8 7a

8

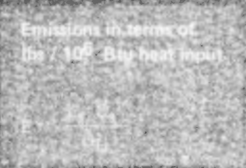
9a


ISOKINETIC CONDITION

10

$$v_s = K_p C_p \sqrt{\frac{T_s \Delta P}{P_s M_s}}$$
PITOT TUBE EQUATION

11


Emissions in terms of
lbs / 10^6 Btu heat input

12

14

Volume Correction

13

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: EPA METHOD 5 SAMPLING TRAIN

COURSE: 450 - Lecture 3
LESSON TIME: 1 hour
PREPARED BY: Giuseppe J. Aldina
DATE: 9/15/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To familiarize the students with the equipment used for EPA Method 5 Particulate sampling; point out construction details required in the August 18, 1978 Federal Register; illustrate equipment design factors influencing sampling accuracy and convenience.

Lesson Objectives:

The student will be able to:

1. List the construction and calibration requirements for the Method 5 sampling nozzle
2. List the nozzle, probe, pitot tube, and thermocouple placement requirements to minimize aerodynamic interferences
3. List the approved construction materials for the nozzle probe, pitot tube, and probe liner
4. Describe the probe locking system for preventing misalignment in the gas stream
5. Describe the advantages and disadvantages of various types of sample cases and glassware
6. List the advantages and disadvantages of various materials used in constructing umbilical lines
7. Describe the advantages of magnehelic gages for pressure measurements and list the requirements for using these gages in an EPA Method 5 Sampling System
8. Compare the cost effectiveness of the nomograph and calculator

Student Prerequisite Skills:

None

Support Materials and Equipment:

1. Course Workbook
2. 8/18/77 Federal Register
3. Slide Projector
4. EPA Method 5 Sampling Train - Nutech

Special Instructions:

None

References:

Federal Register - Vol. 42, No. 160, August 18, 1977. "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8."

The purpose of this lecture is to familiarize you with EPA Method 5 sampling equipment and its construction requirements given in the 8/18/77 Federal Register. The descriptions will start with the sampling nozzle and proceed through the sampling system to the Meter Console.

At the end of this lecture you should be able to:

1. List the construction and calibration requirements for the Method 5 sampling nozzle
2. List the nozzle, probe, pitot tube, and thermocouple placement requirements to minimize aerodynamic interferences
3. List the approved construction materials for the nozzle probe, pitot tube, and probe liner
4. Describe the probe locking system for preventing misalignment in the gas stream
5. Describe the advantages and disadvantages of various types of sample cases and glassware
6. List the advantages and disadvantages of various materials used in constructing umbilical lines
7. Describe the advantages of magnehelic gages for pressure measurements and list the requirements for using these gages in an EPA Method 5 Sampling System
8. Compare the cost effectiveness of the nomograph and calculator

CONTENT OUTLINE

Course: 450 Lecture 3
Lecture Title: EPA Method 5 Sampling Train

Page 1 of 6

NOTES

I. The Sampling Nozzle

Ref. FR 8/18/77 page 41777, paragraph 2.1.1 and p 41781 paragraph 5.1 (Calibration)

- A. Must be made of 316 SS or glass
  - 1. Seamless tubing
  - 2. Other materials must be approved by the Administrator
- B. Must be button-hook on elbow design - unless Administrator approves otherwise

Show nozzle during discussion and illustrate calibration

  - 1. Must have sharp, tapered leading edge
  - 2. Taper must be on the outside with $\leq 30^{\circ}$ taper angle
  - 3. Constant internal diameter should be preserved
- C. Range of nozzle sizes should be on hand - 0.32 - 1.27 cm ID suggested
- D. Calibration - Record results in laboratory logbook
  - 1. Calibrated before initial use in the field
  - 2. Using micrometer measure ID to nearest 0.025 mm (0.001 in)
    - a. Measure 3 separate diameters
    - b. Average the readings
    - c. The difference between the low and high numbers shall not exceed 0.1 mm (0.004 in) or nozzle must be reshaped
  - 3. Nozzles that have been nicked, dented or corroded must be reshaped and recalibrated
  - 4. Each nozzle must have a permanent identification

II. The Pitot Tube - "S" Type is recommended; others may be used with Administrator approval

- A. Construction details and calibration procedures are covered in the lecture on Reference Method 2
- B. Position in relation to the sampling nozzle is of interest here (page 41764 FR 8/18/77)

L3-1
(use slide L7-4)

  - 1. The nozzle entry plane must be even with or below pitot orifice
  - 2. Centerline of orifice and nozzle must agree
  - 3. Minimum separation for 1.3 cm diameter nozzle and pitot tube is 1.90 cm

C. Position of pitot tube in relation to the sampling probe sheath and thermocouple is also important.

   1. The probe sheath end and pitot orifice opening must be separated by a distance of 7.62 cm.

   2. The Thermocouple must either be offset 1.90 cm at the pitot tip or be no closer than 5.08 cm to pitot orifice.

L3-2
(use slide L7-5)

III. The Sampling Probe

A. 2.54 cm in diameter is most useful and prevents probe from becoming a flow obstruction in the duct. This is covered in more detail in RM 2 lecture.

illustrate points discussed with a sampling probe

B. Should be 316 SS or equivalent

C. Pitot tube should be firmly welded to the probe. This helps prevent pitot misalignment

D. The probe should be designed to prevent accidental misalignment in the gas stream

Refer to RM 2 discussion of pitot tube misalignment error

   1. During use it is common to handle the sample train and probe

   2. Very easy to misalign some sampling systems

   3. A good probe will not allow itself to be twisted into misalignment

   4. Misalignment causes errors in velocity measurement

   5. Full evaluation of possible errors owing to misalignment covered in RM 2 lecture

E. Probe should be designed to protect the liner and prevent accidental breakage

   1. Nutech System - glass liner is not exposed to stress and easy breakage

   2. Other systems - glass liner is more exposed to breakage

Compare Nutech Probe - Sample Case interface to some other. Nutech System works very well.

IV. The Probe Liner

A. Must be borosilicate or quartz glass tubing

   1. Must have heating system capable of maintaining exit gas temperature of $120^\circ \pm 14^\circ$C ($248^\circ \pm 25^\circ$F).

      a. Exit temperature calibrated as shown in APTD-0576

      b. Administrator may specify other temperature requirements

Reference: page 41777 FR 8/18/77, paragraph 2.1.2

2. Borosilicate glass liners used up to 480°C (900°F)

3. Quartz glass liners used from 480°C - 900°C (900 - 1650°F)

B. Stainless steel liners (316SS) may be used with the approval of the Administrator

V. The Sample Case

A. Federal Register requirements

1. Filter heating system capable of maintaining a temperature around the filter holder of $120^{\circ} \pm 14^{\circ}$C ($248^{\circ} \pm 25^{\circ}$F)

2. Temperature gage capable of $\pm 3^{\circ}$C (5.4°F) accuracy

B. Desirable features

Nutech Sample case incorporates many of these features. It is good for class illustrations.

1. Light weight

2. Good insulation - hot and cold areas

3. Positive probe alignment locking system

4. Easy accessibility to all parts

5. Good glassware protection

6. Good electrical system

7. Reasonably accurate thermostat for filter chamber and probe heater

8. Single point monorail attachment

9. Durability

10. Flexibility for vertical or horizontal stack traverses

11. Sometimes two piece construction is added convenience - able to separate heated filter and cold impingers

C. Glassware - 2 types; decision on use is personal preference

1. Ball joint

a. Standard type

b. Works well

c. Must use non-volatile silicone grease

d. Grease is inconvenient, messy, and can contaminate sample or catch particulate

2. Compression Fittings(screw type)
    a. More convenient
    b. Reduced contamination probability
    c. Easier to clean
    d. Can, however, increase breakage

VI. The Umbilical Cord

A. The umbilical cord is simply a bundle of lines for:
    1. Vacuum tube
    2. Pitot tubes
    3. Electrical connections

B. It is recommended that:
    1. Keep it simple - don't add too many lines
        a. Makes it heavy
        b. Hard to repair a broken line when so many are wrapped together
    2. Use heavy rubber vacuum tubing for the pump-impinger connection
        a. Not cut easily
        b. Not easily melted or burned
    3. Use Tygon for the pitot tube lines for the same reasons as B2

VII. The Meter Console

A. Meter console encloses the gas metering system illustrated on page 41777 FR 8/18/77 Figure 5.1
    1. An enclosed system is not required but is usually easiest to use
    2. It is recommended that the meter console be a simple system containing
        a. Flow control valves
        b. Pump
        c. Dry gas meter with dialface calibration of 0.1 CFM/Revolution

d. Pitot tube differential pressure gage

3. Communication systems and thermo-couples are cheaper and more useful as separate components

a. Lower initial cost

b. Easier to repair and check

c. Can be used for other applications without the full sample train

B. Desirable features

1. Light weight

2. Reliable leak free pump preferably oil lubricated fiber vane

3. Easy readability

4. Good temperature controls

5. Averaging dry gas meter thermometer (must be accurate to ± 3°C (5.4°F))

6. Rugged construction

7. Good carrying handles

8. Magnehelic differential pressure gages

a. FR 8/18/77 allows magnehelic gages when they agree with 3 oil manometer Δp readings in the duct within 5%

b. Very reliable when properly calibrated

c. Easier to read

d. Less sensitive to vibrations

e. No need to continuously recheck zero setting

VIII. The Nomograph

A. This course covers the derivation of the isokinetic rate equation

1. Nomograph is used to solve the equation for ΔH based on the stack gas variables

2. A calculator can solve the equation more accurately

B. Nomographs must be calibrated

1. Check scale alignment
2. Check accuracy

C. Nomograph is an expensive specialized slide rule

1. Calculator is more accurate and more easily reset
2. Calculators can be used to work up other data. Nomograph does only one calculation

This lecture has covered an overview of the EPA Method 5 Sampling Train. We have

1. Identified individual components
2. Listed FR requirements
3. Pointed out some advantages and disadvantages of different equipment designs

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: DISCUSSION OF LABORATORY EXERCISES

COURSE: 450 - Lecture 4
LESSON TIME: 90 minutes
PREPARED BY: Giuseppe J. Aldina
DATE: 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

4

Lesson Goal:

Provide the students with explanations of the laboratory procedures to be performed in the Monday afternoon Laboratory.

Lesson Objectives:

The student will be able to

1. List the procedures for applying reference Method 1 at circular and rectangular stacks
2. List the steps involved in performing an "S" type pitot tube calibration
3. Describe the procedures for wet bulb-dry bulb moisture estimation
4. Calibrate the meter console orifice meter when the dry gas meter has been calibrated against a reference volume standard.

Prerequisite Skills:

None

Support Materials and Equipment:

1. August 18, 1977 Federal Register
2. Blackboard and chalk
3. slide projector
4. 450 workbook

Special Instructions:

Refer students to FR during the lecture so they may mark important items

References:

Federal Register - Vol. 42, No. 160, August 18, 1977. "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8."

The success of the afternoon laboratory sessions depends upon a thorough understanding of the methods and procedures used. The experience gained in this laboratory will be very useful when actually performing an EPA Method 5 test or any other type of sampling. You (students) will calibrate an "S" type pitot tube, calibrate the meter console orifice meter, perform wet bulb - dry bulb moisture estimates, and apply Method 1 guidelines for sample and velocity traverses. After completing the lab you should be able to:

1. Select a sample site and sampling traverse points following Reference Method 1 Criteria
2. Describe and perform the calibration of a Type S pitot tube
3. Calibrate an orifice meter
4. Estimate the percent moisture in a stack gas

CONTENT OUTLINE

Course: 450 Lecture 4
Lecture Title: Discussion of Laboratory Exercises

Page 1 of 10

NOTES

I. Reference Method 1

Lab exercise covered on page 21 in the workbook

A. Principle

1. Aid in making representative measurements from a stationary source

a. Pollutant emissions

b. Total volumetric flow rate

2. Stack cross-section is divided into equal areas

3. A traverse point is located in each equal area

B. Applicability - The method may be applied to flowing gas streams in any duct, stack, or flue except under any of the following circumstances:

Note paragraph 1.2 page 41755, 8/18/77 FR

1. Cyclonic or swirling gas flow (defined on page 41758 paragraph 2.4) exists in the duct

A description is covered in the procedures section of this lecture (E1).

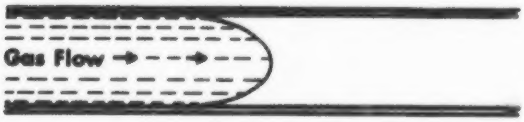
2. The stack is smaller than 0.30 m (12 in.) in diameter or the cross-sectional area is less than 0.71 m^2 (113 in.^{2})

3. The measurement site is less than 2 duct diameters downstream or less than 0.5 diameters upstream from a flow disturbance

C. Description of Laminar Gas Flow

1. Laminar gas flow is a theoretical concept - it may never exist in actual practice

2. Laminar flow in a duct is described in this drawing:



A hand drawing on the board is more effective, here, than a slide

3. The "Bullet" shape of the gas is caused by friction

a. Gas layer closest to the stack wall dissipates some energy as friction and slows down

b. The layer of gas above the boundary layer proceeds to give up some energy contacting the slower more viscous boundary layer

This should remain simple - try not t get bogged down in fluid dynamics

c. This action proceeds - theoretically - in a symmetrical manner across the gas velocity head

4. It is easiest to measure the velocity pressure of a gas when it is in a flow pattern approximating laminar flow

D. Flow Disturbance

1. A flow disturbance is a

   a. Bend in the duct

   b. Expansion or contraction of the duct

   c. Visible flame

Note: Laminar flow may not exist ever but at 8φ and 2φ the assumption is made that the flow reasonably resembles Laminar

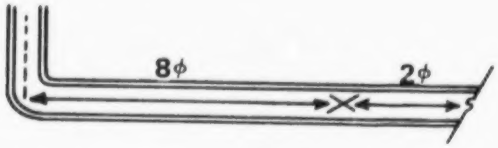
2. At 8 duct diameters downstream and 2 diameters upstream of a flow disturbance

   a. Velocity head profile is assumed to resemble Laminar conditions

   b. The minimum number of sample points may be used

3. Draw flow disturbance at 8φ and 2φ

φ = diameter



Point out that these are minimum criteria There can be more than 8φ and 2φ

When sampling at this point the minimum # of pts may be used - 12 pts.

4. When sampling at a site other than 8ϕ and 2ϕ

   a. You will have to use the chart on page 41756 to determine the number of traverse pts. required

   b. You may not sample at a site that does not have at least 2ϕ downstream and 0.5ϕ upstream of a disturbance

E. Procedures - Circular stacks

1. Determine the following

   a. Duct internal diameter - is it larger than 0.3 meter ?

   b. Cyclonic flow condition using the Type S pitot tube

   Use pitot tube for demonstration; See page 41758 (directly below Figure 1.4)

      1) Prepare differential pressure gage

      2) Connect pitot tube to the gage

      3) Position pitot tube orifice openings perpendicular to the plane of the stack, cross-sectional area-orifice is parallel to the gas flow

      4) At this point the "S" tube should show "0" reading on the gage. (Equal forces will act on both orifice openings)

      5) If the gage does not show "0" rotate the pitot until a "0" reading is shown

      6) Record the rotation angle from the original position

      7) Repeat the procedure for all traverse pts.

      8) Assign traverse pts which require no rotation to reach "0" gage reading a value 0.

      9) Average all readings. If the average of all rotation angles is greater than 10° the duct has an unacceptable flow condition

   c. Duct diameters of "straight run" from all disturbances

2. Based on duct diameters straight run locate the sampling site

a. Choose the most convenient site

b. 8ϕ and 2ϕ not always possible

c. Choose a site that will allow the least number of traverse pts.

3. Use the graph on page 41756 to determine the number of traverse pts. for sampling. Use the graph given for the appropriate duct internal diameter

   a. Remember when reading the graph that both upstream and downstream diameters from a disturbance are important

   b. You can always sample more traverse pts but never are you allowed to sample less than the minimum shown on the graph

   c. The number of pts. must be a multiple of 4

   d. This number is the total traverse pts. Half of these are on each traverse diameter

4. Calculate the percent diameter into the duct from the stack wall for each traverse point.

   a. Use the table 1.2 on page 41758

   b. $\frac{\text{total traverse pts}}{2}$ = pts/diameter

   c. Find the pts./diameter in the table and multiply actual duct ϕ by the decimal % shown

Refer to Figure 1-3 on page 41758.

EXAMPLE:

duct ϕ = 100 cm

total traverse pts = 12

traverse pts/diameter = 6

1st pt = 100 cm x 0.044 = 4.4 cm from stack wall into the duct

2nd pt = 100 cm x 0.146 = 14.6 cm into the duct

5. Locate the traverse pts on 2 perpendicular diameters one of which is in the plane of highest anticipated dust concentration

Refer to page 41757 paragraph 2.3.1 for details

6. Note guides for location of traverse pts. within 2.5 cm of the stack wall in paragraphs 2.3.1 and 2.3.1.1

F. Procedures - Rectangular Ducts

1. Check for cyclonic flow

2. Calculate duct equivalent diameter

$$D_E = \frac{2\ LW}{L+W}$$

3. Determine the duct diameters of straight run

4. Use the appropriate graph on page 41756 to determine No. of traverse pts.

5. Refer to Table 1-1 for the required Balanced Matrix

Check 450 workbook problem section which describes balanced matrix procedure page 165

II. Calibration of the "S" type pitot tube

Lab exercise covered on page 24 in the workbook

A. The complete details of the reference method 2 will be covered in lecture seven.

1. All Federal Register requirements will be highlighted.

2. Today we want to give the procedures for calibration of the "S" tube in the laboratory

B. Equipment

1. Standard pitot-static tube or Prandtl Tube.

2. Inclined oil manometer (use only one)

3. Calibration duct

a. Must have at least 8ϕ and 2ϕ straight run from disturbances

b. Capable of steady gas velocity of 15 m/sec (30-40 ft/sec)

c. Ports must be arranged so Prandtl Tube and "S" Tube would be at the same point in the gas stream

4. Type S pitot tube attached to the sampling probe tube used in Wednesday's source sampling lab, including the sampling nozzle.

5. Laboratory data sheet

workbook page 26

C. Procedures

1. Record identification numbers of all equipment used

2. Level and zero the manometer

3. Check Probe-Nozzle-Pitot tube separations and record

4. Leak check the system
    a. Prandtl tube and tubing to manometer
    b. Pitot tube and tubing to manometer
    c. Recommended leak check is positive pressure at impact opening and negative pressure at static opening to 7.6 cm (3 in) H_2O.
    d. Leak check should be stable for 15 seconds
5. Check the calibration duct for cyclonic flow
6. Mark Prandtl and "S" tube so they will be at the same point in the duct
7. Mark legs A and B of the "S" tube
8. Insert Prandtl tube
    a. Record Δp (when reasonably steady)
    b. Remove the tube

Make sure students keep all pitots properly level and aligned in the duct.

9. Insert leg A of the "S" tube
    a. Record Δp
    b. Remove
10. Insert Prandtl tube
11. Insert leg B of the "S" tube
12. Repeat 8-11 until 3 pairs of readings are completed
13. Measure duct static pressure
14. Record
    a. All Δp readings
    b. Duct static pressure
    c. Duct gas temperature
    d. Actual barometric pressure at the site

15. Calculate

    a. C_p for the "S" tube for each reading

    $$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{(std)}}{\Delta p_{(s)}}}$$

    $C_{p(std)} = 0.99$

    b. Calculate average Cp for leg A and leg B

    c. Average deviation for leg A and B

    $$\sigma = \frac{\Sigma|C_{p(s)} - \bar{C}_p|}{3} \leq 0.01$$

    d. Deviation between leg A and B

    $$\sigma = |\bar{C}_{p_A} - \bar{C}_{p_B}| \leq 0.01$$

16. Calculate

    a. velocity (m/sec)

    $$\bar{v}_s = K_p C_p \sqrt{\frac{T_s}{P_s M_s}} \qquad \sqrt{\Delta p_{avg}}$$

    M_s = 29 for dry air

    b. Volumetric flow rate (m^3/Hour)

    $$Q_s = 3600 (v_s) A_s (1-B_{ws}) \left(\frac{T_{std}}{P_{std}}\right)\left(\frac{P_s}{T_s}\right)$$

    Assume B_{ws} = 0 for this calculation

III. Wet Bulb - Dry Bulb Moisture Estimate

page 27 in workbook

A. The Wet Bulb-Dry Bulb Technique for moisture estimation is used in this laboratory

   1. Reference Method 4 will be discussed later

   2. Wet Bulb-Dry Bulb is easy and can give a good estimate of the H_2O content of the stack gas

B. The % H_2O in the stack is by Dalton's Law of Partial Pressure

   1. $B_{ws} = \frac{V.P_{H_2O}}{P_{abs}}$ Ratio of component partial pressure to total system pressure

   2. The workbook shows the calculation for the actual $V.P._{H_2O}$ using knowledge of

a. The saturated V.P.$_{H_2O}$ at constant temperature and pressure

b. Latent heat of vaporization for H_2O

Note: The wet bulb-dry bulb procedure does not work in acid gas streams

3. The % H_2O can be found using

a. The calculation $B_{ws} = \frac{V.P.}{P_{abs}}$, page 30 of Workbook

b. Psychometric chart page, page C-22 of Course Manual

c. Nomograph page 32 of Workbook

C. Procedure

1. Take dry bulb temperature

2. Take wet bulb temperature

a. Preferably using the same thermometer or one very similar

b. Cover entire area inserted into the duct with a cotton wick, tightly wrapped around the thermometer

c. Saturate wick in H_2O before inserting into the duct

d. Watch temperature rise carefully

e. When temperature rise stops record the temperature

f. Temperature will continue to rise after the momentary pause

3. Use any procedure given in B3. Cross check procedures for agreement if interested

IV. Orifice Meter Calibration

A. APTD - 0576 calibration procedures gives recommended calibration for

workbook page 33

1. Orifice meter

2. Dry gas meter

B. Laboratory exercise will differ only slightly

The lab procedure works well when the DGMCF is known. Assume DGMCF = 1 for these labs.

1. Wet test meter will not be used

2. Dry gas meter correction factor (DGMCF) has been determined against a spirometer

3. We will calibrate orifice meter for the desired flow rate

C. Orifice meter $\Delta H_@$ is a calibration factor. It is the pressure differential across the meter which allows 0.75 CFM flow rate at 29.92 in. Hg Barometric pressure and 68°F.

D. Workbook shows equations used

Workbook page 33

1. $Q_m = K_m \left[\frac{T_m\ ^oR\ \Delta H}{P_m\ M_m}\right]^{\frac{1}{2}}$

2. Solving for ΔH at given conditions

$$\Delta H_@ = \left(\frac{0.75\ \text{CFM}}{Km}\right)^2 \frac{(29.92)\ (29)}{528} = \frac{0.9244}{K_m^{\ 2}}$$

E. Procedure

1. Follow lab instructions

2. Use form on page 36 of workbook

3. Solve equations $\Delta H_@$ should fall within 1.5 - 2.1 in. H_2O or there is probably a mistake

V. Closing Comments

A. A large amount of information has been presented very quickly

1. A great many things to cover, however, if confusion exists it will all come together by Wednesday

Experience has shown this is very true

2. DO NOT become discouraged

B. Laboratory will be

1. Hectic

2. Noisy

C. Instructors will help with all problems

D. You will get as much out of the lab as you put in so apply yourself

E. Be sure to read the workbook carefully. You will be doing

1. Site pre survey - fill out forms

2. Reference Method 1 - complete all drawings

Either have student do this for the best possible situation at the duct or for conditions existing.

3. Pitot tube calibration
4. Moisture estimation
5. Orifice calibration
6. Volumetric flow rate

Sheet on page 41 to be turned in on Wednesday morning.

LESSON PLAN

TOPIC: ISOKINETIC SOURCE SAMPLING

COURSE: 450 - Lecture 5
LESSON TIME: 1 hour 15 minutes
PREPARED BY: J. A. Jahnke
DATE: 9/20/78

Lesson Goal:

To present the concept of isokinetic sampling, providing the rationale of why it is necessary to sample isokinetically for particulate matter.

Lesson Objectives:

The student will be able to:

1. Define isokinetic sampling
2. Illustrate why isokinetic sampling is necessary when sampling for particulate emissions
3. State how the particulate concentration given by the Method 5 train will change when the sampling is performed over isokinetically
4. State how the particulate concentration given by the Method 5 train will change when the sampling is performed under isokinetically.

Student Prerequisite Skills:

Ability to multiply and divide

Support Materials and Equipment:

1. Course workbook
2. Slide projector

Special Instructions:

This lecture is the first of a sequence of three lectures given on isokinetic sampling, Tuesday morning. The three lectures work extremely well together, if presented with a proper appreciation of how fast the students can grasp the concepts.

References:

None

CONTENT OUTLINE

Course: 450 Lecture 5
Lecture Title: Isokinetic Source Sampling

NOTES

I. Review of previous day's material

A. Ask following questions concerning M5 sampling train.

1. Where is the orifice meter?

2. Where does one read Δp? , ΔH?

3. What is Δp related to?

4. What is ΔH related to?

5. What is $\Delta H_@$? — students did this Monday laboratory, but were not formally presented with it in lecture.

$$Q_m = K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

$$\Delta H_@ = \frac{Q_m^2}{K_m^2} \quad \frac{P_m M_m}{T_m}$$

$$\Delta H_@ = \frac{(.75)^2}{K_m^2} \quad \frac{(29.92)\ (29.0)}{(460 + 68)}$$

6. What is the isokinetic sampling condition?

$v_n = v_s$ stress this!

7. What happens in the impingers?

8. Does the same amount of gas (volume) go through the nozzle as goes through the orifice meter, per unit time?

9. How does the pressure and temperature change from the nozzle to the orifice meter?

10. What is pmr., E ?

11. Write the pitot tube equation

12. What is the expression for a volume correction?

To warm up the class it has been found necessary to first review some of the previous day's material. Conduct this part as a question and answer session.

L5-1

Note: These questions are slanted so that the student may be better able to comprehend the Tuesday morning lectures.

II. Isokinetic sampling

A. Definitions and principles

1. Isokinetic

a. "Iso" - denotes equality, similarity, uniformity

b. "kinetic" - pertains to motion

L5-2
Turn to page 45 of workbook.

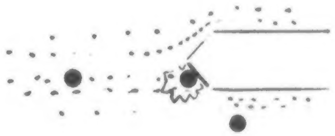
c. Isokinetic sampling is where velocity of gas through probe nozzle is equal to stack gas velocity

2. Principles

a. Large particles tend to move in same initial direction — have enough inertia to deviate from streamline pattern

b. Small particles tend to follow streamlines

c. Intermediate size particles are somewhat deflected.



Draw on chalk board

d. This is watered down aerodynamics for purpose of this lecture — a large particle ≥ 5 μm in diameter — small particle ≤ 1 μm in diameter (This corresponds with EPA's feelings for large and small particle definitions — but you may get some argument)

B. The Example

Refer back to L5-2

1. 100% Isokinetic sampling — what would be the concentration collected?
Note: Assume a large particle weighs 6 mass units and that we have a small particle weighing .03

$$v_n = v_s$$

$$\text{Mass rate} = M_n = (4\text{x}6)+(4\text{x}.03)\ \frac{\text{mass units}}{\text{minute}}$$

$$\text{Flow rate} = Q_n = 1\ \text{ft}^3/\text{minute}$$

$$\therefore \text{concentration} = \frac{\text{mass rate through nozzle}}{\text{volumetric flow rate through nozzle}}$$

$$= \frac{24.1}{1}\ \frac{\text{mass units}/\text{mi}\cancel{\text{nute}}}{\text{ft}^3/\text{mi}\cancel{\text{nute}}}$$

$$= 24.1 \frac{\text{mass units}}{\text{ft}^3}$$

2. 200% Isokinetic
Larger volume collected per unit time – large particles not sliced out by nozzle, are lost. All smaller particles in volume are collected.

L5-3

$v_n = 2v_s$

$Q_n = 2 \text{ ft}^3/\text{min}$

$$\therefore C_n = \frac{(4x6)+(8x.03)}{2}$$

$$= \frac{24.2}{2} = 12.1 \frac{\text{mass units}}{\text{ft}^3}$$

Over isokinetic sampling gives concentration lower than true

3. 50% Isokinetic

L5-4

Smaller volume collected per unit time large particles don't follow streamlines, but punch into nozzle.

$v_n = \frac{1}{2} v_s$

$Q_n = .5 \text{ ft}^3/\text{min}$

$$C_n = \frac{4x6 + (4x.03)}{.5}$$

$$= 48.2 \frac{\text{mass minutes}}{\text{ft}^3}$$

Under isokinetic sampling gives higher concentration than true.

4. Generalizations:

   a. 100% Isokinetic – gets representative particulate distribution on filter

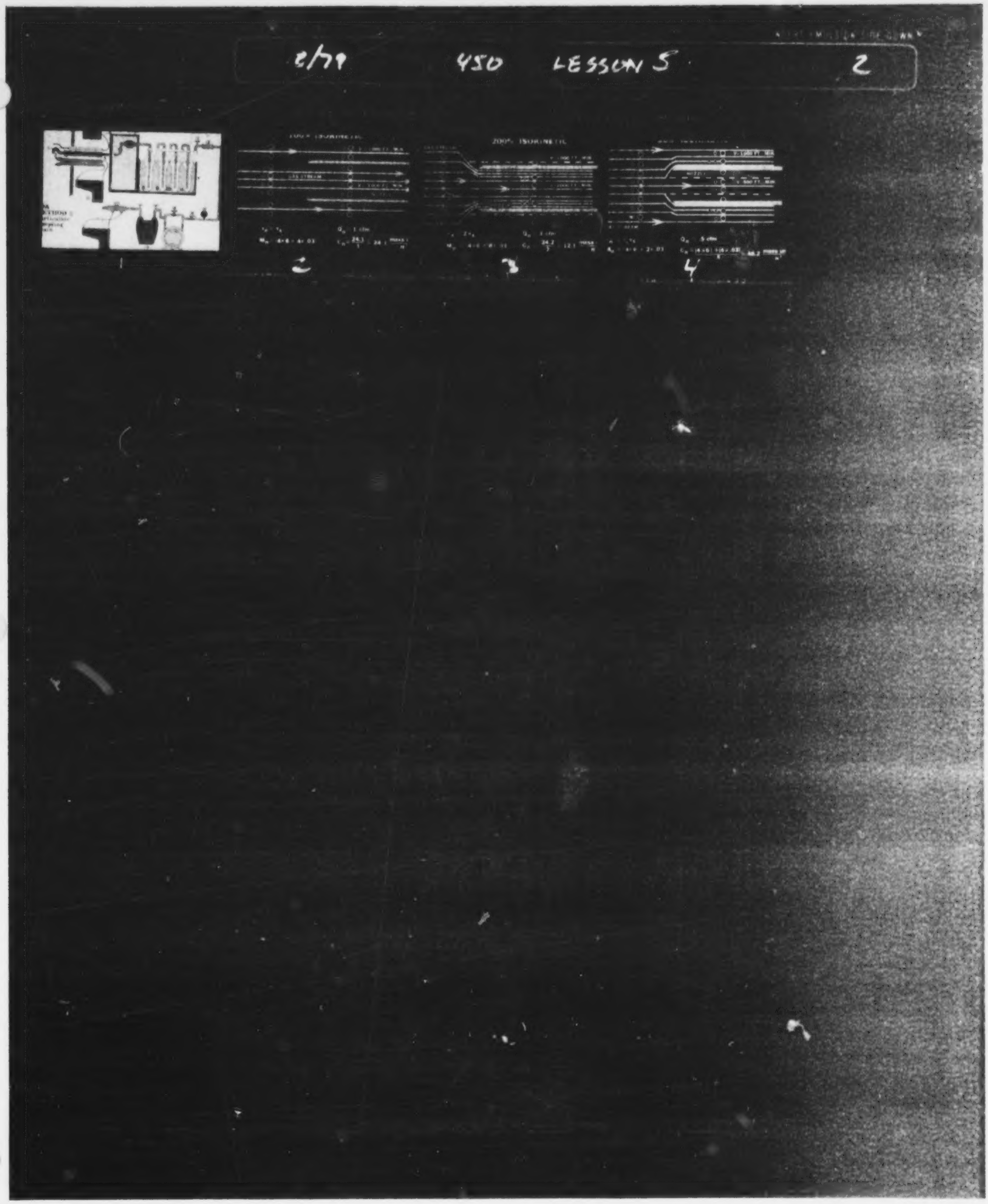
   b. Over isokinetic -get lower weight of particles per amount of volume due to loss of large particles through inertia effects

c. Under isokinetic -get more weight of particles per amount of volume due to addition of large particles punching through streamlines.

d. These are generalizations — may have exceptions in special cases — refer to references given on page 47 of course workbook.

C. The Question — Problem is, how does one sample isokinetically? — Given the EPA Method 5 train, how is it set up so that $v_n = v_s$?

Go immediately on to next lecture. Class should still be fresh and interested. Don't take a break, or attention will be lost.


8/79
450
LESSON 5
2
100% ISOKINETIC
200% ISOKINETIC
1
2
3
4

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: THE ISOKINETIC RATE EQUATION

COURSE: 450 - Lecture 6
LESSON TIME: 1 hour 15 minutes
PREPARED BY: J. A. Jahnke DATE: 9/20/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

6

Lesson Goal:

To derive the isokinetic rate equation for the EPA Method 5 train, from basic principles of the ideal gas law, and to present methods for its solution.

Lesson Objectives:

The student will be able to

1. Recall the basic equation for establishing the isokinetic rate, $\Delta H = K\Delta p$.
2. Explain that gas passing through the sampling train undergoes changes of moisture content, temperature, and pressure.
3. Explain that the isokinetic rate equation is derived from the requirement that v_n must equal v_s, and that one obtains the final expression by substituting the pitot tube equation and orifice meter equation and by making proper corrections for pressure, temperature, and moisture content.
4. Recognize the fact that a separate equation exists for the determination of the nozzle diameter
5. Calculate the value of D_n, the nozzle diameter, given the appropriate input data, using a calculator or a slide rule
6. Calculate the value of K and ΔH, given the appropriate input data, using a calculator or a slide rule
7. Calculate values of D_n, K, and ΔH using a source sampling nomograph
8. State the assumptions of the source sampling nomograph
9. Check the accuracy of the source sampling nomograph and recognize the effect of errors in computed ΔH values on test results.

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Intended Student Background:

High school math and high school or college general science. Attendance at 1st day laboratory mandatory for comprehension of this lecture.

Support Materials and Equipment:

1. Course workbook
2. Slide projector
3. Pocket calculator with square root function, for each student — or slide rule to do extended calculations
4. One source sampling nomograph for each student

Special Instructions:

Some students may "turn off" when they realize you are going to derive an equation. Never tell them that you are doing a derivation — just do it as if it proceeds logically out of the last lecture — don't make a big deal out of it. Approximately ½ of the class will be lost or won't care about the equation after the derivation is finished (depending upon your presentation abilities). Immediately after the derivation, the students are to calculate the problem given on page 59 of the workbook. The students that didn't care, will now care very much, especially if you go around from student to student to see how they are doing.

References:

Yergovitch, T. W., "Development of a Practical Source Sampling Slide Rule", JAPCA 26 #6 June 1976, pp 590-592

CONTENT OUTLINE

Course: 450 Lecture 6
Lecture Title: The Isokinetic Rate Equation

Page 1 *of* 8

NOTES

I. Derivation of the Isokinetic Rate Equation — L6-1

A. $\Delta H = K\Delta p$ — The relationship between v_s and v_n. Note that get Δp from pitot tube — Set the ΔH calculated from this equation with the orifice meter. This makes $v_n = v_s$ Ask following questions:

1. On what oil manometer do we read Δp?
   Ans. - red

2. On what oil manometer do we read ΔH?
   Ans. - Yellow oil manometer

3. How is the ΔH set? Ans. - with fine control knob. (students should know this from lab, but ∿ ½ the class will not understand it yet)

This is the core o course. Once the student understands this concept, he is half way home to doing the method. Slower students may not grasp this until Wednesday afternoon.

B. $Q_n = A_n v_n = A_n v_s$ under isokinetic conditions — L6-2

What is the area of the nozzle?

$$A_n = \pi\left(\frac{D_n}{2}\right)^2$$

Therefore

$$Q_n = \frac{\pi D_n^2}{4} v_s$$ is the volumetric flow rate through the nozzle

C. What is the volumetric flow rate through the orifice meter? — L6-3

$$Q_m = k_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

This equation was used in Monday afternoon lab and should have been reviewed in 1st ½ hour Tuesday morning

D. If the stack gas contained no moisture, how would Q_n be related to Q_m? Would it be the same? No — because have change of temperature and pressure through the train. — L6-4

$$Q_n = \frac{P_m}{P_s} \; \frac{T_s}{T_m} \; Q_m$$

For lecturer's information don't give in class unless asked

Since

$$P_sV_n = n_sRT_s \qquad P_mV_m = n_mRT_m$$

$$n_s = n_m \text{ (since have no } H_2O)$$

$$V_n = \frac{P_m}{P_s}\ \frac{T_s}{T_m}\ V_m \text{ or } Q_n = \frac{P_mT_s}{P_sT_m}\ Q_m$$

E. Now, if stack contains moisture — L6-5

$$n_s\ (1 - B_{ws}) = n_m\ (1 - B_{wm})$$

$n_s\ (1 - B_{ws}) = n_m$ if use silica gel i.e. the number of moles of gas at stack conditions is made up of combustion gases and water. The fraction of combustion gases $(1 - B_{ws})$ times n_s, gives n_m.

F. Flow rate corrected for T, P, and moisture, is now — L6-6

$$Q_n = \left(\frac{1 - B_{wm}}{1 - B_{ws}}\right)\ \frac{T_s}{T_m}\ \frac{P_m}{P_s}\ Q_m$$

Since

$$P_sV_n = n_sRT_s \qquad P_mV_m = n_m\ RT_m$$

$$n_s = \frac{(1 - B_{wm})}{(1 - B_{ws})}\ n_m$$

$$P_sV_n = \frac{(1 - B_{wm})}{(1 - B_{ws})}\ n_mRT_s$$

$$\text{but } n_m = \frac{P_mV_m}{RT_m}$$

Do not give this derivation in lecture unless asked. It is too involved and you will lose most of the class if you give it — it would also waste too much time.

therefore

$$\left[\begin{aligned}
P_s V_n &= \frac{(1 - B_{wm})}{(1 - B_{ws})} \quad \frac{P_m V_m}{\cancel{R}\, T_m} \quad \cancel{R} T_s \\[2ex]
V_n &= \frac{(1 - B_{wm})}{(1 - B_{ws})} \quad \frac{P_m T_s}{P_s T_m} \quad V_m \\[2ex]
Q_n &= \frac{(1 - B_{wm})}{(1 - B_{ws})} \quad \frac{T_s}{T_m} \quad \frac{P_m}{P_s} \quad Q_m
\end{aligned}\right]$$

G. Solution is then:

$$Q_n = \frac{(1 - B_{wm})}{(1 - B_{ws})} \quad \frac{T_s P_m}{T_m P_s} \quad K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

substituting for Q_m

H. Now substitute for Q_n L6-8

$$\frac{\pi D_n^2}{4} \quad v_s = \frac{(1 - B_{wm})}{(1 - B_{ws})} \quad \frac{T_s P_m}{T_m P_s} \quad K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

I. What is the pitot tube equation? L6-9

$$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$$

J. Substitute L6-10

$$\frac{\pi D_n^2}{4} \, K_p C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}} = \frac{(1-B_{wm})}{(1-B_{ws})} \quad \frac{T_s}{T_m} \quad \frac{P_m}{P_s} \, K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$$

K. Simplifying L6-11

$$\Delta H = \left\{ D_n^{\,4} \left(\frac{\pi K_p C_p}{4K_m} \right) \frac{(1-B_{ws})^2}{(1-B_{wm})^2} \; \frac{M_m}{M_s} \; \frac{T_m P_s}{T_s P_m} \right\} \Delta p$$

L. Note moisture relationships for molecular weight L6-12

$$M_m = M_d\,(1 - B_{wm}) + 18\,B_{wm}$$

$$M_s = M_d\,(1 - B_{ws}) + 18\,B_{ws}$$

M. Substitute to obtain Isokinetic rate equation L6-13

$$\Delta H = \left\{ D_n^{\,4} \left(\frac{\pi K_p C_p}{4K_m} \right)^2 \frac{(1-B_{ws})^2}{(1-B_{wm})^2} \left[\frac{M_d(1-B_{wm}) + 18\,B_{wm}}{M_d(1-B_{ws}) + 18\,B_{ws}} \right] \frac{T_m P_s}{T_s P_m} \right\} \Delta p$$

N. Now want to get above equation into a working form using all of our constants and variables /L6-14

Define $\Delta H_@$ as the orifice pressure differential that gives 0.75 cfm of air at 68°F and 29.92"Hg

O. Substitute values into orifice meter equation L6-15

$$\Delta H = \frac{Q_m^{\,2}}{K_m^{\,2}} \; \frac{P_m}{T_m} \; M_m$$

$$\Delta H_@ = \frac{(.75\text{ cfm})^2\,(29.92\text{ in. Hg})(29.0)}{(460 + 68^{\circ}\text{F})K_m^{\,2}}$$

$$\Delta H_@ = \frac{.9244}{K_m^{\,2}}$$

P. Assume the following — L6-16

$B_{wm} = 0$

$\Delta H_@ = \frac{.9244}{K_m^2}$

$K_p = 85.49$

Q. Isokinetic rate equation working form — L6-17

$$\boxed{\Delta H = \left\{846.72\ D_n^4 \Delta H_@ C_p^2\ (1-B_{ws})^2\ \frac{M_d}{M_s}\ \frac{T_m}{T_s}\ \frac{P_s}{P_m}\right\} \Delta p}$$

R. Similarly, one can derive an expression for the nozzle diameter — L6-18

$$\boxed{D_n = \sqrt{\left(\frac{0.035\ Q_m P_m}{T_m C_p}\right)\ \frac{(1-B_{wm})}{(1-B_{ws})}\ \sqrt{\frac{T_s M_s}{P_s \Delta p}}}}$$

S. Immediately turn to page 53 of the course workbook and have the students do the lecture problem. — Do not take a break

Ans:

$M_s = M_d(1-B_{ws}) + 18\ B_{ws}$

$M_s = 29\ (1-.12) + 18\ (.12) = 27.7$

$$D_n = \sqrt{\left(\frac{0.0357\ Q_m P_m}{T_m C_p}\right)\ \frac{1}{(1-B_{ws})}\ \sqrt{\frac{T_s M_s}{P_s \Delta p}}}$$

$$= \sqrt{\frac{(0.0357)\ (.75)\ \ (30.0)}{(540)\ (.85)}\ \frac{1}{.88}\ \sqrt{\frac{(740)\ 27.7}{(29.6)\ (.80)}}}$$

$= \quad .241$

choose .25" nozzle

Tell the class to choose a .25" nozzle after they have completed the first part of this calculation

then

$$\Delta H = \left[846.72\ D_n^{\,4} \Delta H_@ C_p^{\,2}\ (1-B_{ws})^2\ \frac{M_d}{M_s}\ \frac{T_m}{T_s}\ \frac{P_s}{P_m}\right] \Delta p$$

$$= \left\{846.72\ (.25)^4\ 1.85(.85)^2(.88)^2\ \frac{29}{27.7}\left(\frac{540}{740}\right)\ \left(\frac{29.6}{30.0}\right)\right\} \Delta p$$

$$= 2.59\ \Delta p$$

$$\Delta H = 2.59\ \Delta p$$

T. Ask questions:

What do you do if Δp = 1.0
.80
.60

Say if moving probe from traverse point to traverse point — get new Δp's at each point, calculate and set new ΔH's at each point.

How do you set the ΔH?

Now take a break. Have each student pick up a nomograph during the break.

II. Using the nomograph to solve the isokinetic rate equation

A. The nomograph - A type of slide rule to do the calculations given in I. Show several types of nomographs. Show several types of other slide rule calculators. Mention prices - Nomograph \$140
Slide rule \$40 → \$140

B. Assumptions of the nomograph

1. Assume

C_p = .85

T_m = 530°R

$\Delta H_@$ = 1.84" H_2O

$P_s = P_n = 29.92''Hg$

$M_d = 29.0$

$B_{ws} = .05$

Substitute into

$$\Delta H = \left[846.72 \ D_n^{\,4} \Delta H_@ C_p^{\,2} (1-B_{ws})^2 \ \frac{M_d}{M_s} \ \frac{T_m}{T_s} \ \frac{P_s}{P_m} \right] \Delta p$$

get

$$\Delta H = K_@ C \ \frac{D_n^{\,4}}{T_s} \ \Delta p$$

$K_@ = 5.507 \times 10^5$

C is a correction factor

2. C Factor

L6-19

a. C factor corrects for $\Delta H_@$, T_m, % H_2O, P_s, and P_m

b. C does not correct for C_p or M_d

C. Using the nomograph

1. Compute C factor using data for previous lecture problem

Ask students value of C factor they obtain.

C should = .91 or .92

2. Turn nomograph over — compute nozzle diameter

$D_n = .241$

3. Compute K and ΔH using nomograph and choosing nozzle diameter of .25"

L6-20
work along with students. Ask students for values obtained.

K = 2.59 when Δp is set = 1

Show use of nomograph to obtain ΔH from Δp's

4. Nomograph check for scale alignment. Fill in table given in slide

L6-21
Ask for student comments.

D. Errors in calculating ΔH

1. Calculator and equation, the best way
   - a. Problems with battery discharging
   - b. Punching numbers or operations incorrectly (Magnetic and programs minimize this)
   - c. Soiling with fly ash (put calculator in plastic bag)

2. Nomograph
   - a. Can get errors up to 10% of true for ΔH values - this will contribute approximately a 5% error to the % isokinetic.
   - b. Check out nomographs at pretest meeting.
   - c. Many stack samplers are used to nomographs and find them to be more convenient than calculators.

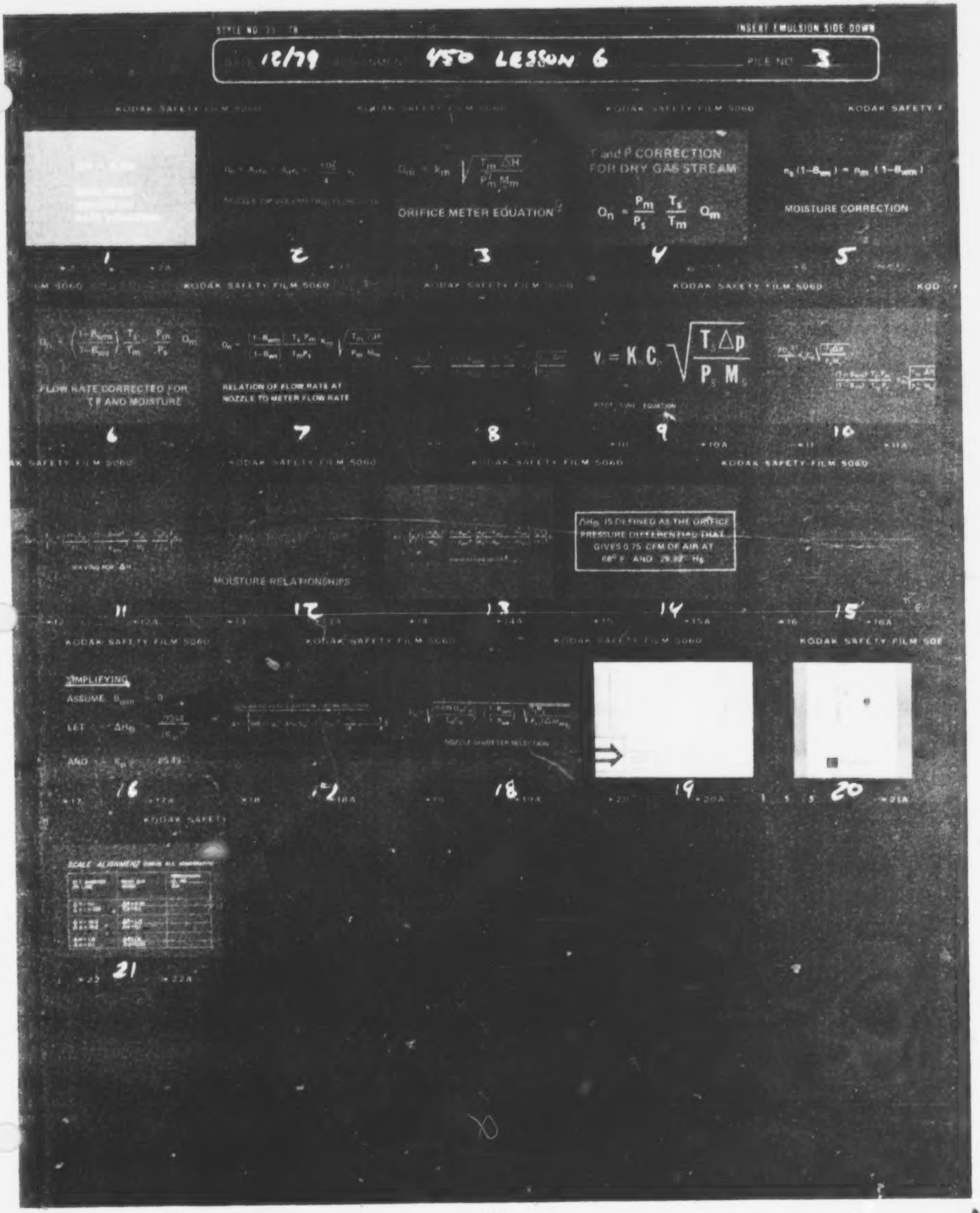
3. Slide rule calculators
   - a. More accurate than nomograph, less accurate than calculator.
   - b. Smaller, convenient
   - c. Problem with scales moving.

4. Microprocessors
   - a. Available through Radar - Glass Innovations.
   - b. Expensive.
   - c. Save some work, but stack sampler not doing much during this period of test anyway.

5. Choice of ΔH calculation method is that of individual - just be sure that method is done correctly.

III. Assign homework problem - page 57 of Workbook. Ask to hand in page 59, with answers, Wednesday.

NOTE: It is sufficient to do problems 1 & 3.



STYLE NO. 35 7B

INSERT EMULSION SIDE DOWN

12/79 450 LESSON 6 FILE NO. 3

1

2

3

$Q_m = K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$

ORIFICE METER EQUATION

4

T and P CORRECTION FOR DRY GAS STREAM

$Q_n = \frac{P_m}{P_s} \frac{T_s}{T_m} Q_m$

5

$n_s(1-B_{ws}) = n_m(1-B_{wm})$

MOISTURE CORRECTION

6

$Q_n = \left(\frac{1-B_{wm}}{1-B_{ws}}\right) \frac{T_s}{T_m} \frac{P_m}{P_s} Q_m$

FLOW RATE CORRECTED FOR T,P AND MOISTURE

7

$Q_n = \frac{(1-B_{wm})}{(1-B_{ws})} \frac{T_s P_m}{T_m P_s} K_m \sqrt{\frac{T_m \Delta H}{P_m M_m}}$

RELATION OF FLOW RATE AT NOZZLE TO METER FLOW RATE

8

9

$v_s = K_p C_p \sqrt{\frac{T_s \Delta p}{P_s M_s}}$

PITOT TUBE EQUATION

10

11

SOLVING FOR ΔH

12

MOISTURE RELATIONSHIPS

13

14

$\Delta H_@$ IS DEFINED AS THE ORIFICE PRESSURE DIFFERENTIAL THAT GIVES 0.75 CFM OF AIR AT 68° F AND 29.92" Hg

15

16

SIMPLIFYING

ASSUME $B_{wm} = 0$

LET $\Delta H_@ = \frac{.9244}{(K_m)^2}$

AND $K_p = 85.49$

17

18

NOZZLE DIAMETER SELECTION

19

20

21

SCALE ALIGNMENT

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: Review RM1; RM2; RM4; RM3

COURSE: 450 Lecture 7
LESSON TIME: 2 hours 30 minutes
PREPARED BY: DATE:
Giuseppe J. Adlina 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

Illustrate to the students the proper methods for completing RM1 and RM2. Explain the RM4 method for moisture determination. Explain the RM3 procedures for gas analysis.

Lesson Objectives:

7

The student should be able to:

1. Fully describe and perform RM1 procedures
2. List all Federal Register requirements for pitot tube calibration, construction, and use
3. Describe RM4 procedures for moisture determination
4. Use RM4 equations for calculation of B_{ws}
5. List the procedures for RM3 gas analysis
6. Calculate and mathematically define
   a. M_d
   b. M_s
   c. % Excess air

Prerequisite skills:

None

Level of Instruction:

College undergraduate science

Preceding page blank

Intended Student Profesional Background:

General Science

Support Materials and Equipment

1. FR 8/18/77
2. Blackboard and chalk
3. Slide projector
4. 450 Workbook
5. Standard pitot
6. S-type pitot tube
7. Orsat apparatus

Special Instruction:

Point out the important sections to the students in FR 8/18/78. This lecture has a great deal of latitude. Students generally show interest in all sections. Concentrate on areas of greatest student interest as indicated during the lecture.

References:

Federal Register - Vol. 42, No. 160, August 18, 1977. "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8."

This lecture is divided into several discrete sections:

I. Review of the Sample and Velocity Traverse Procedures for RM1

II. Detailed Evaluation of "S" Type Pitot Tube Calibration and RM2

III. Discussion of RM4 - Determination of Moisture in Stack Gas

   A. Procedures

   B. Calculations

IV. Discussion of RM3 - Gas Analysis for CO_2, Excess Air and Dry Molecular Weight

   A. Procedures

   B. Calculations

After the RM3 discussion we will proceed to the laboratory for practice in using the Orsat apparatus for gas analysis.

CONTENT OUTLINE

Course: 450 Lecture 7
Lecture Title: Review RM1; RM2; RM4; RM3

Page 1 *of* 11

NOTES

I. Review of RM1 procedures

(The review should be done with the instructor drawing the schematic diagrams necessary for RM1 procedures from FR 8/18/77. Class input should be requested to assist in making the drawings).

II. Reference Method 2 - Determination of Stack Gas Velocity and Volumetric Flowrate

A. Principle

1. Average stack gas velocity is determined from the gas density and average velocity pressure head

$$\bar{v}_s = K_p C_p \sqrt{\frac{T_s}{P_s M_s}} \cdot \left[\Delta p\right]^{1/2}_{\text{Average}}$$

Note: v_s may be approximated

Assuming $P_s = 30$;
$M_s = 30$
$C_p = 0.85$
$v_s = 2.46\sqrt{T_s \Delta p}$

2. The gas velocity and stack cross-sectional area are used in calculating the average standard dry gas volumetric flow rate

$$\bar{Q}_s = 3600(\bar{v}_s)(A_s)(1-B_{ws})\left(\frac{T_{std}}{P_{std}}\right)\left(\frac{P_s}{T_s}\right)$$

B. Applicability

1. Not applicable to sampling sites that do not meet RM1 criteria

2. If cyclonic flow exists

   a. Install gas straightening vanes

   b. Calculate the total volumetric flowrate stoichiometrically

   c. Move to another sampling site

C. Standard or Prandtl Pitot tube design specifications

Slide L7-1

1. The Standard or Prandtl pitot tube has specific design criteria accepted by the National Bureau of Standards

2. (Point out construction details shown on the L7-1 slide)

3. The construction of this tube following these criteria has shown

    a. Turbulence around the measuring orifices it does not occur to any significant amount that could affect readings

    b. Gas stream orientation sensitivity is greatly reduced

    c. The calibration coefficient (C_p) is generally 0.99 ± 0.01

Note: It is more convenient and clearer to students to refer to C_p as the calibration coefficient

4. The C_p of the standard pitot tube may be determined by NBS, however, the FR allows the user to assume $C_p = 0.99 \pm 0.01$

5. An "S" type tube must be calibrated against a Prandtl or standard tube

6. The Prandtl tube is not generally used for source sampling

    a. Static pressure taps may be plugged in a heavy particulate gas stream

    b. The long impact opening section is difficult to get into standard diameter ports

D. The "S" type (Stausscheibe) pitot tube

Slide L7-2

1. The Federal Register now includes construction details for the "S" type tube

2. The Federal Register describes

    a. Proper tube alignment

    b. Appropriate sizes of tubing for construction

    c. Preferred plane of the orifice openings

Slide L7-3

    d. Proper configuration with the probe and sampling nozzle to minimize aerodynamic interferences

Slides L7-4 L7-5

AIR POLLUTION TRAINING INSTITUTE

CONTENT OUTLINE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Course: 450 Lecture 7

Lecture Title: Review RM1; RM2; RM4; RM3

Page 3 of 11

NOTES

3. When all construction and placement requirements are met the baseline coefficient C_p for the "S" type may be assumed to be 0.84. (Refer to FR page 41764, paragraph 4.1 and 4.1.1)

Note: FR language states "eliminate" interferences, references specifically state "minimize"

Ask class laboratory groups:

1. How many calculated a C_p different than 0.84?
2. How much different?
3. What conclusion would they draw?

Students should recognize the need for calibration of the "S" tube C_p.

E. Calibration of the "S" type tube

Slide L7-6

1. Equipment

L7-7
L7-8

a. Calibration duct

1) Proper port openings

2) 8 and 2 diameters minimum

3) Capable of steady gas flow

a) Single pt. calibration 700 m/min (2000ft/min) or about 30-40 ft/sec

b) 4 pt. calibration - variable from 180-1525 m/min(600-5000ft/min) at regular intervals

Note: The single pt. calibration is accurate to ±3% above 305m/min and ± 6% from 180-305 m/min. A 4 pt. calibration is therefore preferable

b. Pitot tubes

L7-9

c. Inclined manometer - sensitivity is stated in paragraph 2.8 FR page 41762

L7-10 - No need to dwell on sensitivity just refer students to FR if necessary.

d. A mock-up port surrounded by circular graph paper is shown in these slides so we may discuss misalignment errors of the "S" type tube.

L7-11; L7-12

2. Procedures

   a. Check for duct blockage

$$2\% \geq \frac{\begin{pmatrix}\text{length of Probe} \\ \text{in duct}\end{pmatrix} \times \begin{pmatrix}\text{Probe} \\ \text{diameter}\end{pmatrix}}{\text{Duct area}} \times 100$$

   b. Check for cyclonic flow - pitot tube may be used as in FR or streamers can be effective — L7-13; L7-14

   c. Remember if the pitot tube is oriented as shown a proper flow condition is indicated by a zero reading on the manometer — L7-15

   d. The velocity profile across the duct may resemble these readings — L7-16, 17, 18, 19

   e. Mark the standard pitot tube and "S" type so they will be at the same place in the gas stream — L7-20

   f. Insert the standard tube with the "S" type tube removed and record the Δp — L7-21

   g. Insert leg A of the "S" tube and record ΔP — L7-22

   h. Repeat this procedure for leg B

   i. Collect 3 sets of readings for leg A and B at each velocity used for the calibration — L7-23, 24, 25

   j. Plot the data for the readings — L7-26

      a. This is actual NBS data for an "S" type tube calibration

$$C_p = \sqrt{\frac{1}{K}}$$

      b. K plotted against Reynold's Number gives a very detailed description of all gas parameters

      c. It is sufficient for source sampling purposes to plot K versus gas velocity — L7-27

3. Misalignment errors

a. During the course to this point we have mentioned misalignment errors

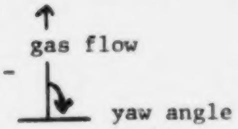
L7-28

L7-29

1) The "S" type pitot tube does not measure the correct gas velocity vector unless it is aligned parallel with the stack wall - perpendicular to the gas flow

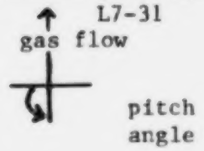
L7-30

2) Turning the pitot tube out of perpendicular - giving it a yaw angle - produces velocity measurement errors



L7-31

3) We will evaluate yaw alignment errors. Pitch errors are much less critical and do not become evident unless gross pitch error is made



b. Examining the theoretical pressure distribution in a duct and the ΔP readings we would get using an "S" type tube and rotating it through 90° of yaw angle we can plot the data

L7-32

L7-33

Stop on slide L7-33 and point out % error in velocity readings versus degree yaw misalignment. Cyclonic gas flow creates the same problems.

Ask if there are questions on the method

This should strongly point out to the student the need for careful alignment of the "S" tube and the problems caused by cyclonic flow.

III. Discussion of Reference Method 4 - Determination of Moisture Content in Stack Gas

It is necessary to determine stack gas moisture content so measured volumes can be corrected to dry standard conditions and the volumetric follow rate of the stack gas can be calculated on a dry basis.

A. Principle - Reference method only

1. A gas sample is extracted

2. The moisture in the gas is removed by passing through the cooled impingers (as in Method 5 train)

3. The volume of H_2O removed is measured volumetrically or gravimetrically

B. Appliciability

1. The reference method using the Method 5 sampling train is designed for accurate moisture determination in the stack gas

2. The reference method is often conducted simultaneously with pollutant emissions measurement

   a. Method 4 is actually combined with Method 5 during a particulate run

   b. Only the H_2O trapped in the combined run is used for reference method moisture determination

   c. This means that even if RM4 is run along with Method 5 only the H_2O in the Method 5 train is considered reference method moisture

3. The reference method can yield questionable results in saturated gas streams or streams that contain H_2O droplets

   a. Under these conditions a second H_2O determination is made

   b. The second H_2O determination may be done using stack temperature and a psychrometric chart or vapor pressure tables or by alternate method approved by the administrator

   c. We used wet bulb - dry bulb

      1) Makes a good estimate of H_2O in the gas

      2) Quick

      3) Only H_2O in Method 5 is actual RM H_2O so wet bulb-dry bulb is a good way to

         a) Save time

         b) Get H_2O estimate for nomograph calculcations

         c) Could be used as 2nd method for H_2O in saturated gas streams

C. Procedures

1. RM4 procedures use the RM5 sampling train

2. The RM4 system requires RM5 operation with the following variations

   a. Sample at a constant rate ± 10%

   b. Traverse at least 8 pts in the duct

   c. Sample rate maximum = $0.021 m^3/min$ (0.75cfm)

   d. Minimum sample volume = 0.6 scm (21 scf)

   e. Run time shall = RM5 run time

3. Since we will be operating RM5 this discussion will be all that we alot to RM4

D. Calculations

1. The Ideal gas law

$$PV = \frac{m}{M} RT$$

2. Solving for volume

$$V = \frac{mRT}{PM}$$

3. Substituting $\rho_{H_2O} V_{liq} = m$

$$V_{wc} = \frac{\rho_{H_2O} V_{liq} RT}{PM}$$

4. Then at standard conditions the H_2O collected in the impingers can be converted to standard cubic volume by:

   a. $$V_{wc(std)} = \frac{(V_f - V_i) \rho_{H_2O} RT}{P_{std} M_{H_2O}}$$

b. Replacing known terms and solving

$$V_{wc_{(std)}} = K_1 (V_f - V_1)$$

$$K_1 = 0.04707 \text{ ft}^3/\text{ml}$$

$$K_1 = 0.001335 \text{ m}^3/\text{ml}$$

5. The same equation is solved to convert grams of H_2O caught in the silica gel to vapor with the simplified equation written:

$$V_{wsg_{(std)}} = K_2 (W_f - W_i)$$

$$K_2 = 0.04715 \text{ ft}^3/\text{ml}$$

$$K_2 = 0.001335 \text{ m}^3/\text{ml}$$

6. The dry gas volume metered at standard conditions is

$$V_{m_{(std)}} = V_m \frac{\left(P_{bar} + \frac{\Delta H}{13.6}\right)\left(T_{std}\right)}{P_{(std)}\, T_m}$$

This is the equation in the Federal Register. To be completely correct it should include a dry gas meter correction factor (Y)

7. The mole fraction of H_2O is then

$$B_{ws} = \frac{V_{wc_{(std)}} + V_{wsg_{(std)}}}{V_{wc_{(std)}} + V_{wsg_{(std)}} + V_{m_{(std)}}}$$

IV. Reference Method 3 - Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight

Note: Tell the class that we will cover the sample procedure and calculations then go to the lab to practice the Orsat

RM3 gas analysis yields data used in calculating the percent excess air in a duct; stack gas molecular weight; and process emission rate using the F-Factor.

A. Principle

1. A gas sample is extracted from the stack
   - a. Single pt. grab sample
   - b. Single pt. integrated sample
   - c. Multi pt. integrated sample
   - d. Multi pt. grab sample

2. The sample is analyzed for CO_2, O_2, CO using an Orsat analyzer or Fyrite

Slides
L7-34 = Orsat
L7-35 = Fyrite

   a. The Orsat must be used for

      1) Excess air calculations

      2) Emission rate calculations based on the F-Factor

F-Factor:

$$E = C_s F_d \left[\frac{20.9}{20.9-\%O_2}\right]$$

covered later in the course

   b. Fyrite may be used when only the dry molecular weight of the gas is needed

B. Applicability

1. Applicable for CO_2, O_2, CO, excess air, and dry molecular weight determinations from fossil-fuel combustion processes

2. May be used at other processes where other compounds are present in the stack gas if these compounds are not in high enough concentration to effect the results

3. Other methods and modifications may be used with administator approval

C. Procedures - Emission Rate and Excess Air

1. Check the FR subparts for appropriate procedure

   a. Single pt. grab sample → Sample probe no closer than 1 meter to stack wall

   b. Multi pt. integrated sample

   c. Multi pt. grab sample

   (b, c) → At least 8 traverse pts in the duct. Follow RM1 procedures

2. The procedures given here are for emission rate and excess air determinations

   a. The data for these procedures is the most critical

   b. It is good practice to use these procedures for all determinations

   c. These collect the greatest amount of data

3. Sample train - draw train shown on page 41769 FR 8/18/77

4. Train operation - general for all procedures

   a. Leak check the train at 250 mm Hg (10 in Hg) following paragraph 3.2.2 page 41770

   b. Position the probe at the traverse point

   c. Purge sampling lines

   d. Sample at a constant rate and equal length of time at each traverse point

   e. Sample for the same period and simultaneously as the Method 5 sample

   f. Collect at least 30 liters (1CF) of stack gas

   g. Analyze using the Orsat

5. Orsat Analysis

   a. Analyze sample within 4 hrs after extraction

   b. Leak check the Orsat

      See workbook Page 67

      1) Bring bubbler solutions to reference marks

      2) Bring burette solution to mid scale and record reading

         This requires thorough instructor explanation

      3) Let apparatus sit for 4 minutes

      4) If all solutions still at reference marks leak check is OK. Find any leaks noted

   c. Analyze the stack gas

      1) CO_2 read directly as $\%CO_2$

      2) O_2 is cumulative so

         $\%O_2 = (CO_2 + O_2) - \%CO_2$

      3) CO is also cumulative so

         $\% CO = (CO_2 + O_2 + CO) - (\%O_2 + \%CO_2)$

      4) N_2 is determined by difference

         $100 - (CO_2 + O_2 + CO) = \% N_2$

d. Calculations

1. Dry molecular weight (M_d)

$$M_d = 0.44(\%CO_2) + 0.32\ (\%O_2) + 0.28\ (\%N_2) + 0.28(\%CO)$$

2. Apparent wet molecular weight (M_s)

$$M_s = M_d(1-B_{w_s}) + 18(B_{w_s})$$

3. % Excess Air

$$\%EA = \frac{\%O_2 - 0.5\ (\%CO)}{0.264(\%N_2) - \%O_2 + 0.5(\%CO)} \times 100$$

This is the correct equation FR 8/18/77 page 41771 Equation 3-1 is wrong.

Proceed to Orsat Laboratory - The Orsat Lab is designed for practice only. Students will need instructor demonstration of Orsat procedures and careful attention during the practice session.

2/79 450 LESSON 7 4

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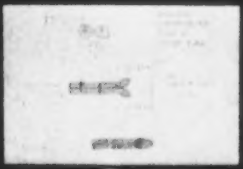
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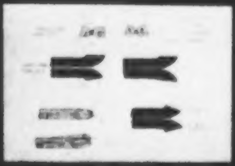
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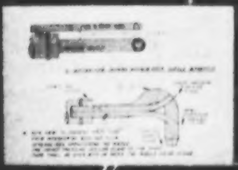
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EXPERIMENT # 1

CALIBRATION OF 'S' TYPE TUBE

6

EQUIPMENT

7

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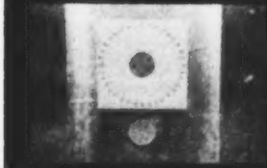
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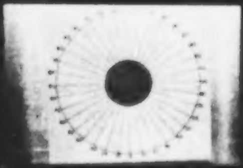
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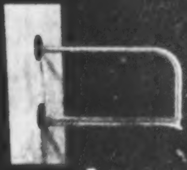
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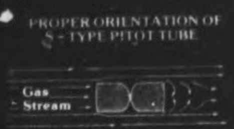
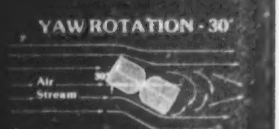
EXPERIMENT # 2

MISALIGNMENT ERRORS

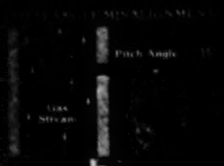
28


PROPER ORIENTATION OF
S - TYPE PITOT TUBE
Gas
Stream
29

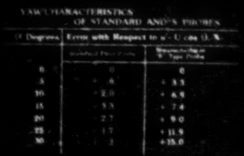

YAW ROTATION - 30°
Air
Stream
30°
30

[illegible] EMULSION SIDE DOWN

12/79 450 LESSON 7 5

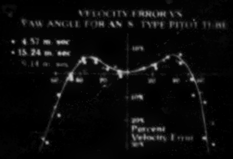

MISALIGNMENT
Pitch Angle
Gas Stream

31


YAW CHARACTERISTICS OF STANDARD AND S PROBES

θ Degrees	Error with Respect to u' = U cos θ, %	
	[illegible] Pitot Probe	Stauscheibe or S Type Probe
0	0	0
5	+ .6	+ 3.5
10	+ 2.0	+ 6.9
15	+ 3.5	+ 7.4
20	+ 2.7	+ 9.0
25	+ 1.7	+ 11.9
30	[illegible]	+ 15.0

32



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34

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LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: CALCULATION AND INTERPRETATION
OF % ISOKINETIC

COURSE: 450 - Lecture 8
LESSON TIME: 1 hour 45 minutes
PREPARED BY: J. Jahnke DATE: 9/21/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

8

Lesson Goal:

To present the concept of % isokinetic, derive the expression given for % I in the Federal Register, and present the method used for evaluating the adequacy of source tests which are not 100% isokinetic.

Lesson Objectives:

The student will be able to:

1. Locate the equations for %I in the Federal Register and in the course workbook.
2. Explain how the %I expression is derived.
3. Explain the relative importance of the variables in the %I expression and point out which ones should be closely checked on the source test report.
4. Illustrate the effect of underisokinetic sampling on the measured pmr, relative to the true pmr.
5. Illustrate the effect of overisokinetic sampling on the measured pmr, relative to the true pmr.
6. Evaluate whether a source test should be rejected or accepted, based upon the value of the % isokinetic and whether the emission rate value is above or below the standard.

Student Prerequisite Skills:

Ability to multiply and divide and to have deductive reasoning ability.

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

High school math and general science.
Understanding of previous day's material is important for this lecture.

Support Materials and Equipment:

1. Course workbook
2. Federal Register - Vol. 42, No. 160, August 18, 1977. "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8."
3. "A Guideline for Evaluating Compliance Test Results"- A Monograph by R. Shigehara
4. Slide projector

Special Instructions:

This is an important lecture for agency people. The latter part of the lecture, however, is difficult for some people. One should proceed carefully and slowly in this presentation. Hand out the monograph by R. Shigehara at the end of the lecture - not before, or everyone will immediately turn off. For those who don't understand the lecture, the monograph will serve as a "cookbook" procedure for them.

References:

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CONTENT OUTLINE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Page 1 of 6

NOTES

Course: 450 Lecture 8

Lecture Title: Calculation and Interpretation of % Isokinetic

I. Derivation of the % Isokinetic Equation

L8-1

Page 72 in workbook

A. Expression given in Federal Register
Refer to 42 FR 41782 August 18, 1977
Equations 5-7 and 5-8

B. %I indicates how well the source tester was able to achieve the ΔH's required for isokinetic sampling.

C. %I is not an indication of the accuracy of the test. Ex. - If one drops the filter paper and loses particulate matter, this does not show up in the %I calculation

Stress Point C.

D. %I value is important to source tester and agency operator since it provides one of the bases for accepting or rejecting a test, as given in paragraph 6.12.

1. If $90 \leq \%I \leq 110$ tests are acceptable

2. If $E <$ standard and $\%I < 90$, test can be accepted. (on approval by Administrator)

3. If $E >$ standard and $\%I > 110$, test can be accepted (on approval by Administrator)

These concepts are difficult for some students. Explain later, at end of lecture.

E. Derivation

1. $\%I = \frac{v_n}{v_s} \times 100$ "definition"

L8-2

2. From the equation of continuity

$$v_n = \frac{Q_n}{A_n}$$

L8-3

3. Q_n from collected data

L8-4

$$Q_n = \frac{V_{sw} + V_{\text{meter corrected}}}{\theta}$$

where θ = sampling time period

4. Correction of volume metered at orifice, to stack conditions

$$V_{\text{orifice corrected to stack conditions}} = \left(\frac{T_s}{P_s}\;\frac{\left(P_b + \frac{\Delta H}{13.6}\right)}{T_m}\right)V_{meter}$$

L8-5

stress that all are really doing is relating the volume of gas going through the orifice meter to that going through the nozzle

5. Correction for water collected in impingers

$$V_{lc}\,\rho_{H_2O} = M_{H_2O}$$

$$P_sV_{sw} = \frac{m}{M}RT_s$$

and

$$V_{sw} = m_{H_2O}\,\frac{RT_s}{M_{H_2O}P_s}$$

$$V_{sw} = V_{lc}\,\rho_{H_2O}\,\frac{RT_s}{M_{H_2O}P_s}$$

= the volume of water vapor at stack conditions.

Note:
V_{LC} = volume of liquid collected in impingers and silica gel. Silica gel volume obtained from weight difference using Fig. 5-3 42 FR 41780 Aug. 18, 1977.

L8-6

6. Substituting T & P correction into Q_n

$$Q_n = \frac{T_s}{P_s}\;\frac{\left[V_{lc}K_3 + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{\theta}$$

where $K_3 = \frac{\rho_{H_2O}R}{M_{H_2O}}$ =.00267 in Hg ft^3/ml $^\circ$R

L8-7

point out value of K_3 in paragraph 6.12 so they will believe you.

7. Substituting into %I expression L8-8

$$\%I = \frac{v_n}{v_s}\,100 = \frac{Q_n}{v_s A_n}\quad 100$$

$$\%I = \frac{\frac{T_s}{P_s}\left[K_3 V_{1c} + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{A_n\ \theta v_s}\ 100$$

8. %I - Federal Register Expression L8-9

$$\%I = \frac{100\ T_s\left[V_{1c}K_3 + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{60\ \theta\ v_s P_s A_n}$$

9. %I FR expression from intermediate data L8-10

$$\%I = K_4\ \frac{T_s V_{m(std)}}{P_s v_s A_n \theta (1-B_{ws})}$$

$K_4 = 0.09450$ for English units

Note that all this is, is

$$\frac{v_n}{v_s} \times 100$$

where v_n is obtained from V_m which is corrected back to nozzle conditions.

10. Special features of the expression

   a. A_n is in ft^2 or m^2

      (42 FR 41781 paragraph 6.1 nomenclature)

   b. Values for A_n should be extended to 4 or 5 decimal places - be wary of rounding off.

   c. A source test observer should check the values of A_n, B_{ws} and V_{LC}, since small changes in these values can have a great effect on the value of %I. A source tester may attempt to alter the value of %I by modifying these input values, so that the test will be approved without question. The student should be warned about this.

F. Acceptable results

L8-11

1. Review of $\overline{pmr}$

$$pmr = \frac{m_n}{V_n} \underbrace{A_s \bar{v}_s}_{Q_s}$$

[Pmr is an older terminology. For pmr calculate by the concentration method. pmr_a is calculated by the ratio of areas method.]

2. Effect of non-isokinetic conditions on the $pmr_{measured}$ value

L8-12

a. First consider small particles < 1 μm under or over isokinetic sampling will not matter, since particles will follow streamlines and $\frac{m}{v}$ will not vary

good review of Tuesday morning concepts

b. Second, consider large particles > 5 μm under isokinetic sampling → get too high a concentration because large particles punch into probe and collect too much mass for a smaller volume. This varies as 1/v

Over isokinetic sampling → get too low of a concentration because get too few large particles for the larger volume collected. This varies as 1/v

c. If plot $\frac{pmr_{measured}}{pmr_{true}}$ vs the % isokinetic, obtain the plot of given on page 76 of Workbook

L8-12

d. An actual particle distribution will lie somewhere in between.

e. Question:

If a test is done at 80% I and the value of the emission rate is below the standard, should the test be accepted or rejected?

This is an extremely important point. Efforts should be made to see that the students understand this.

Answer:

Accepted, since if the test was conducted at 100% I, the value of the emission rate would be even lower. This is obvious from the graph.

Point out on graph, difference of

$pmr_{meas.}$ at 80% > $pmr_{measured}$ at 100%

f. Question:

same comment

If a test is done at 120% I and the value of the emission rate is above the standard, should the test be accepted or rejected?

Answer:

Accepted, since if the test was conducted at 100% I, the value of E would be even higher and still above the standard

$pmr_{measured}$ at 120%

<

$pmr_{measured}$ at 100%

g. Question:

In the previous question, if the results of the test meant that a $5,000,000 piece of control equipment would have to be installed, would you still accept the test?

Answer:

Debate

Note that if a test is not 100% Isokinetic, the value for C_s will be wrong. The above arguments are for an agency's use.

If a source operator needed the information to size a particulate control device, the above arguments are useless in giving him the right answer. Paragraph 6.12 is only a consideration to be used for agency test approval, and doesn't have too much to do with the value of the emission rate.

Note also that if a test is 100% isokinetic, in no way does this imply that the value of C_s, pmr, or E obtained, is the true value. Errors other than those due to not achieving the calculated emission rate may arise.

These may be the following:

1. Wrong input of variables into isokinetic rate equation will give wrong ΔH's. This, however, will not appear in % I calculation.
2. Errors in nomograph will similarly not show up in % I calculation.

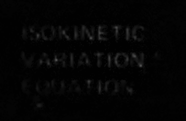
G. Causes of a test not being 100% isokinetic several reasons why a test may be out of isokinetic, are:

1. Moisture guessed wrong in setting isokinetic sampling rates.
2. Inability to follow rapid fluctuations in Δp and corresponding calculated ΔH's. Negative flow
3. Heavy grain loading — plugging filter so can't achieve ΔH's at end of the test.
4. Large temperature variations not corrected in rate calculation
5. Leak in pitot or sampling lines (broken probe, lopsided filter, broken frit)

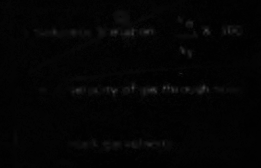
H. Handout — "A Guideline for Evaluating Compliance Test Results" - A Monograph by R. T. Shigehara.

This is EPA policy and may be used as a guideline for administrative approval of tests < 90% or > 110% isokinetic.

12/79 450 LESSON 8 6



ISOKINETIC VARIATION EQUATION

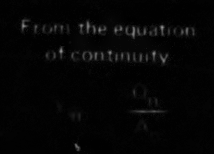


% Isokinetic Variation = $\frac{v_n}{v_s} \times 100$

v_n = velocity of gas through nozzle

v_s = stack gas velocity

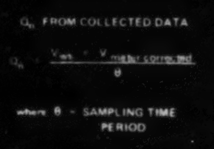
2



From the equation of continuity

$v_n = \frac{Q_n}{A_n}$

3

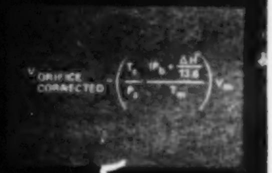


Q_n FROM COLLECTED DATA

$Q_n = \frac{V_{ws} + V_{meter\ corrected}}{\theta}$

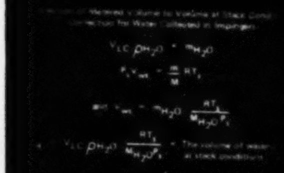
where θ = SAMPLING TIME PERIOD

4



$V_{ORIFICE\ CORRECTED} = \left(\frac{T_s}{P_s}\frac{(P_b + \frac{\Delta H}{13.6})}{T_m}\right)V_m$

5



Conversion of Metered Volume to Volume at Stack Conditions Correction for Water Collected in Impingers

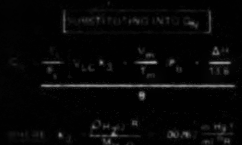
$V_{LC}\rho_{H_2O} = m_{H_2O}$

$P_s V_{ws} = \frac{m}{M} RT_s$

$V_{ws} = m_{H_2O}\frac{RT_s}{M_{H_2O}P_s}$

$V_{LC}\rho_{H_2O}\frac{RT_s}{M_{H_2O}P_s}$ = The volume of water at stack conditions

6

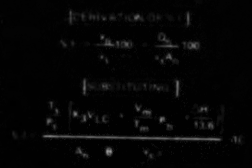


SUBSTITUTING INTO Q_n

$Q_n = \frac{\frac{T_s}{P_s}\left[V_{LC}K_3 + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{\theta}$

WHERE $K_3 = \frac{\rho_{H_2O}R}{M_{H_2O}} = 0.0267\ \frac{in.\ Hg\ ft^3}{ml\ °R}$

7



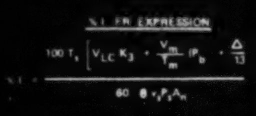
DERIVATION OF %I

$\%I = \frac{v_n}{v_s}100 = \frac{Q_n}{v_sA_n}100$

SUBSTITUTING

$\%I = \frac{\frac{T_s}{P_s}\left[K_3V_{LC} + \frac{V_m}{T_m}\left(P_b + \frac{\Delta H}{13.6}\right)\right]}{A_n\ \theta\ v_s}100$

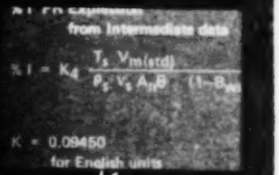
8



% I FR EXPRESSION

$\%I = \frac{100\,T_s\left[V_{LC}K_3 + \frac{V_m}{T_m}(P_b + \frac{\Delta}{13}\right.}{60\ \theta\,v_sP_sA_n}$

9

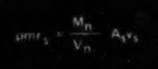


% I FR Expression from Intermediate data

$\%I = K_4\frac{T_s\ V_{m(std)}}{P_s\ V_s\ A_n\theta\ \ (1-B}$

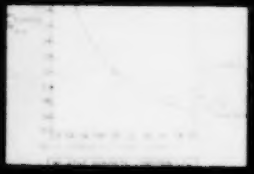
K = 0.09450 for English units

10



$pmr_s = \frac{M_n}{V_n}A_sv_s$

11



12

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: SAMPLING TRAIN CONFIGURATIONS:
DEFINITION OF A PARTICULATE

COURSE: 450 Lecture 9
LESSON TIME: 15 minutes
PREPARED BY: DATE:
Giuseppe J. Aldina 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To point out to students the legal and scientific definitions of a particulate. Show students how sampling train is set-up and how physical operation can affect the particulate definition.

Lesson Objectives:

The student should be able to:

1. *Write the Federal Register definition of a particulate given in the NSPS regulations.
2. Describe the sampling train parameters effecting the definition of a particulate.
3. Define "particulate" for the sampling train configurations given on page 78 of the workbook.

9

Prerequisite Skills:

None

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. Federal Register - Vol 43, No. 37, February 23, 1978, Part V, "Kraft Pulp Mills"
2. 450 Workbook
3. 450 Manual

*Originally given in FR 12/23/71. Has been updated several times in various FR's. Best example is FR 2/23/78 Part V, page 7584 Introduction.

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The course up to this point has dealt with the reference method procedures for particulate source sampling. We have presented the bulk of the procedures required to get a sample from a stack gas. Now we want to direct more attention toward the type of sample we take and the various parameters which can effect the final emissions calculations. This lecture begins this phase of the course. We will define a particulate both legally and scientifically.

CONTENT OUTLINE

Course: 450

Lecture Title: Lecture 9
SAMPLING TRAIN CONFIGURATIONS:
DEFINITION OF A PARTICULATE

Page 1 of 4

NOTES

I. Legal Precedent — The Clean Air Act

A. New source performance standards

1. The Clean Act gives EPA a mandate to protect our air resources

2. The Act sets the policy for Standards of Performance

Refer to manual, page 9-1 for precise language

a. The term "Standards of Performance" means a standard for emissions of air pollutants which reflects the degree of emission limitation achievable through the application of the best system of emission reduction which (taking into account the cost of achieving such reduction) the Administrator determines has been adequately demonstrated.

b. This is important for it indicates political and economic realities which are reflected in the subparts pertaining to emission sources

B. Legal definition of particulate — FR 12/23/71 page 24878 Subpart D, § 60.41, (C)

"Particulate matter means any finely divided liquid or solid material other than uncombined water as measured by Method 5."

Ask if anybody knows this for Federal and state regulations

C. The legal definition refers to the scientific definition for particulate

Ask if anyone readily distinguishes the difference

1. The legal definition is stated in (B)
2. The scientific definition is given by RM5
3. Remember that the subparts give specific guides and requirements for sampling procedures at an affected facility
4. These are all related to the Clean Air Act mandate
    a. The act does not state complete elimination of air pollution must be achieved
    b. NSPS requirements are written with control equipment technology and cost in mind
    c. The sampling methods can measure total emissions from a source
    d. The subparts specify the sampling methods used to test emissions

e. The point is that the sampling method may not measure all emissions from source - It tests emissions as required in the regulations

f. The regulations may vary to give the source some economic relief

D. Example

1. The nominal operating temperature of RM5 filter holder is 120° ± 14°C (248° ± 25°F)

2. However, the FR 10/6/75 page 46258 § 60.46, 5(b) states that RM at a fossil-fuel fired steam generator may have a filter holder and probe operating at 160°C (320°F)

Does this effect the particulate catch?

3. Yes

Why?

4. At 320°F SO_2 and sulfuric acid mist will pass through the filter into the impingers

a. RM5 includes particulates caught in the nozzle, probe liner, and on the filter mat

b. SO_2 can form sulfates on the filter mat at temperatures below approximately 270°F

c. H_2SO_4 can be condensed on the filter mat and in the probe at temperatures below 250°F

d. 320°F assures neither SO_2 or H_2SO_4 is included in the particulate catch

1) An ESP alone would have a tough time Controlling these to meet NSPS

2) An ESP and scrubber would surely handle this problem but can be expensive.

3) This strategy is now in line with the statement of reasonable cost factors

5. These items illustrate all the points we have discussed
    a. There is a legal and scientific definition for a particulate
    b. The scientific definition is RM5
    c. Particulates caught in RM5 are determined partly by
        1) Operating temperature of the probe filter
        2) Portions of the train analyzed

II. Sampling Train Configurations

A. The sampling train set-up, operating temperature, and segments analyzed effect the definition of particulate

B. We want to examine several sampling train configurations to determine the effect on the definition of a particulate
    1. This may be important in designing source sampling experiments
    2. It is important to be sure a sampling train meets the requirements of state and federal agencies when doing compliance testing
    3. It gives some background for possible modifications to a sampling system that may
        a. Make the job easier
        b. But not effect the particulate catch we would get using the straight RM5 system

C. Sample Trains (workbook page 78)

Get the class to join in describing the particulate catch for each system

1. Reference Method 5 - Particulate defined
    a. Probe - filter temperature
    b. Analysis procedures
2. Configuration 1 - Particulate defined
    a. Condenser conditions
    b. Analysis procedure

3. Configuration 2
   - a. Probe-filter temperature
   - b. Second filter may have particulate at condenser conditions
   - c. Analysis
4. Method 17 (Configuration 2)
   - a. Stack temperature
   - b. Analysis
   - c. May yield results significantly lower than RM5

Hand out Feb 23, 1978 FR on Kraft Pulp Mills at this point.

This "definition of a particulate" discussion points out the important legal and scientific aspects of the particulate sampling method and its relationship to the Clean Air Act mandate. The discussion shows that careful preparation must go into planning stack tests to meet test goals, agency regulations, and allow reasonable sampling procedures. This leads us into the discussion on designing a stack test and performing our laboratory.

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: DISCUSSION OF SOURCE SAMPLING EXERCISES

COURSE: 450 Lecture 10
LESSON TIME: 1 hour 15 minutes
PREPARED BY: DATE:
Giuseppe J. Aldina 10/02/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To familiarize students with the procedures for designing, planning, and performing a stack test; the basic operation of the EPA Method 5 sampling train; and present a usable report writing format.

Lesson Objectives:

The student should be able to:

1. List the steps involved in designing a stack test
2. List the information necessary in a pre-survey of the stack test site
3. Recall the planning steps for a stack test
4. Recall a usable report writing format
5. Describe the basic procedures for performing an EPA Method 5 test including filling out data forms and making calculations

10

Prerequisite Skills:

Knowledge of operating requirements for RM5 procedures and equipment (RM1, RM2, RM3, and RM4)

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

General Science

Support Materials:

1. Manual page 7-1
2. Workbook pages 80-81, 79
3. Programmed calculation sheet

Special Instructions:

This lecture is an explanation of the manual and workbook flow charts, outlines and exercises for the EPA Method 5 test

References:

None

This lecture will center on discussion of the flow chart on workbook page 80-81. This flow chart contains our thoughts and opinions on every aspect of planning and performing a source test. After we have discussed the items on page 80 we will go on to the workbook laboratory exercise on page 82. Writing a source test report will be covered last.

CONTENT OUTLINE

Course: 450 Lecture 10
Lecture Title: DISCUSSION OF SOURCE SAMPLING EXERCISES

Page 1 of 6

NOTES

I. Designing a stack test

A. Determine stack test necessity

1. A stack test for compliance to regulations is obvious

Use flowchart and these notes for the discussion

2. Often stack tests yield valuable process operation data

B. Research the literature - Refer to flow chart section

1. This is extremely important

2. Provides information as given in flow chart

C. State test objectives

1. With test necessity and research it is now possible to write complete test objectives

2. Objectives are extremely important

a. Every experiment in science has objectives written prior to beginning the work

b. Experiments are then designed to meet the objectives

c. Experimental work then evaluated in terms of meeting, proving, or disproving the objectives

d. Treat each stack test as an original scientific experiment - IT IS an original experiment

Stress this point - Take no part of the test for granted

D. Design the experiment - follow the flow chart descriptions

E. Do a pre-survey - follow the flow chart

NOTE:
This is not to imply that Method 5 is an experimental method. It has been well proven and documented over the past 10 yrs. The statements are given to instill an attitude which is held by the authors.

1. A pre-survey is often overlooked

a. To cut costs

b. It is assumed there will be no problems

2. A pre-survey

a. Can save time and money in the long run

b. Makes the job easier

c. Allows much better planning and experiment design

F. Finalize test plans - follow the flow chart

G. Prepare equipment - this is obvious and we have been doing the type of preparation necessary in our laboratories

1. An important point to make is for the test team to carry plenty of spare equipment

2. Test all equipment before leaving for the job site

H. Confirmations

1. Travel and accommodations are extremely important

2. Be sure the process is operating at desired level before starting travel

I. Arrival at the site - follow flow chart

1. Inform plant contact of your arrival

2. Review the test plan with all persons involved in the program

3. Confirm sampling site and process operation

This concludes the first part of our lesson concerning the design and planning of the source test. Now we want to proceed to the laboratory exercise on page 84. in the workbook to cover items on performing the source test.

I. Equipment preparations

A. Check the nozzle

1. Round tip opening

2. Calibrate the nozzle using a micrometer as described on Monday morning

B. The sampling probe

1. These items have been done by the laboratory staff to save time for sampling

2. They should be checked routinely prior to use

C. Sample case - again this has been done by the staff

D. The impingers are filled by the staff and assembled The procedure is straight forward and you will get some hands on experience during the disassembly at the end of the test

E. Check the umbilical line and meter console

F. The sampling train leak test

1. The completely assembled sampling train is now ready for a leak test
2. For clarity we will go directly on with the leak test
    a. At an actual test several tasks could be performed while waiting for the train to come up to operating temperature
    b. A suggested sequence will be presented after we cover the leak test
3. Bring all train components to operating temp.
4. Turn the fine adjust valve fully counter clockwise - open
5. Be sure coarse adjust valve is closed
6. Turn on the pump
7. Seal nozzle opening
8. Slowly open the coarse valve - fully open
9. Turn the fine adjust valve (by pass valve) slowly in a clockwise direction
10. Watch the vacuum gage as it proceeds toward 380 mm (15 in) Hg
    a. Do not exceed 380 mm Hg
    b. If you do exceed 380 mm Hg
        1) Slowly release vacuum at the nozzle or
        2) Leak test at the vacuum reached
    c. Do not turn the fine adjust valve counter clockwise at anytime during the leak test

11. Time the leak rate using the dry gas meter and a stopwatch. The leak must be less than 0.00057 m^3/min (0.02 cfm)

12. After timing the leak rate

    a. If it passes requirements record the leak rate and slowly release vacuum at the nozzle

    b. If the train has an unacceptable leak release vacuum at the nozzle then

        1) Track down the leak

        2) Re-test

This is the basic method in the FR. The procedure described therein is more elaborate and should be followed if wanting to meet the letter of regulations.

II. Organization on the stack and in the lab

  A. Turn to the flow chart on page 80.

  B. We have covered to this point

    1. Equipment calibration

    2. Laboratory preparations before testing

    3. Train assembly

    4. Leak testing

  C. Several of these items can be going on simultaneously

    1. This will save time which is important on site

    2. Suggestions are

      a. 1 Technician assemble equipment for the test

      b. 1 Technician take measurements for RM1 requirements

      c. Team leader prepare data forms and equations

    3. After taking RM1 data

      a. Team leader makes RM1 calculations

      b. Technicians assemble traversing system

4. RM1 data completed

   a. Mark traverse points on probe

   b. Do velocity traverse - quick preliminary

   c. Do H_2O estimate

5. While the train is coming to operating temperature for leak test

   a. 1 Technician prepare RM3 equipment

   b. Team leader solve isokinetic equations and fill out data sheets

   c. 1 Technician prepare other sampling trains for runs 2 and 3

6. When ready perform leak test

7. After leak test

   a. Add ice to the impinger bath

   b. Record dry gas meter starting reading

   c. Inform plant of test about to start

   d. Position equipment at point 1 in the stack

   e. Record all data and calculate ΔH desired

   f. Start test and record time

8. The train remains on during the traverse in the port

   a. 15 seconds before time is up at a traverse point move train to next point - this allows Δp on the manometer to stabilize

   b. Record time interval readings

   c. Calculate new ΔH from Δp

9. When the port test time is over stop the train then move to next port

10. Repeat the procedures outlined for each port

11. Be constantly aware during the test of:

    a. Test times

    b. Dry gas meter revolutions

    c. Stack temperature

    d. Sample case temperature

    e. Pump vacuum

    f. Impinger temperature

    g. ΔH versus Δp readings

D. At the end of the test

1. Remove the sample case and probe from the stack with the pump off

2. Record

    a. End time

    b. Dry gas meter final reading

3. Let the train cool then seal the nozzle. Clean-up should be done in a laboratory or other clean area

Clean-up is not done in lab except for measuring H_2O. Procedures are given in manual page 5-12.

III. Data sheet and calculations

A. Data averages

1. Dry gas meter volume sampled - V_m = final - initial dry gas meter reading

2. Average ΔH - straight arithmetic average

3. Average square root of the Δp readings

4. Average stack temperature

B. Calculations - use programmed sheet and explain to students

IV. Report writing - manual page 7-1.

A. This is straight forward and can be done by following the manual sections.

B. If time is tight instruct students to read the section as homework

LESSON PLAN

AIR POLLUTION
TRAINING INSTITUTE

TOPIC: CONCENTRATION CORRECTIONS AND PROBLEM SESSION

COURSE: 450 - Lecture 11
LESSON TIME: 1 hour 15 minutes
PREPARED BY: J.A. Jahnke DATE: 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To introduce methods of correcting emissions data from combustion sources to different types of standard conditions.

Lesson Objectives:

The student will be able to:

1. Discuss the relationships that exist in fossil fuel-fired boilers between excess air, % O_2, and % CO_2
2. Define excess air
3. Correct a particulate concentration to standard temperature and pressure
4. Correct a particulate concentration to 50% excess air using two methods
5. Correct a particulate concentration to 12% CO_2
6. Correct a particulate concentration to 6% O_2

Student Prerequisite Skills:

Ability to multiply and divide

Intended Background:

General Science

Level of Instructions:

College undergraduate math

Materials:

1. Workbook
2. Manual
3. Slide Projector
4. Calculators

Special Instructions:

This is the first lecture Thursday morning. The pace of the course has been rather rapid and perhaps overwhelming to some students. Lectures on Thursday are intentionally slower paced so that the students may have an opportunity to digest the material and ask questions on points previously covered which may not be clear.

References:

Course Manual - Appendix

CONTENT OUTLINE

Page 1 of 4

NOTES

Course: 450 - Lecture 11
Lecture Title: CONCENTRATION CORRECTIONS AND PROBLEM SESSION

I. Correction of concentration to standard temperature and pressure

Page 98 Workbook
L11-1

A. Did this in first lecture, using ideal gas law derivation is:

$$V_{\substack{corr\\std}} = \frac{mRT_{std}}{MP_{std}} \qquad V_s = \frac{mRT_s}{MP_s}$$

$$\frac{V_{\substack{corr\\std}}}{V_s} = \frac{\frac{T_{std}}{P_{std}}}{\frac{T_s}{P_s}} = \frac{T_{std}P_s}{T_sP_{std}}$$

$$V_{corr} = V_s \frac{P_sT_{std}}{P_{std}T_s}$$

$$C_{corr} = \frac{M}{V_{corr}} = C_s \frac{P_{std}T_s}{P_sT_{std}}$$

$$C_{corr} = C_s \frac{P_{std}T_s}{P_sT_{std}}$$

B. Need to first correct data to standard temperature and pressure before doing other corrections

C. In EPA reference methods:

Standard Temperature = 68°F

Standard Pressure = 29.92"Hg

II. Excess Air Corrections

A. Stoichiometric air vs. excess air

1. If you burn carbon stoichiometrically, what do you get? Gas, just CO_2 and N_2 left over.

L11-2

2. Boiler operation — most combustion sources can't run stoichiometrically, need more air. Fuel in combustion zone of boiler will deplete immediate region of oxygen. New fuel entering region will lack enough oxygen to burn completely and will have incomplete combustion. Need to add excess air.

3. When adding excess air, get different percentages of CO_2 and O_2, based upon type of fuel and amount of excess air.

Point on graph

B. Definition of Excess Air:

L11-3

1. $$\% \text{ EA} = \frac{\text{Volume Excess Air}}{\text{Theoretical Volume required for complete combustion}} \times 100$$

2. $$\% \text{ EA} = \frac{\% O_2 - .5 (\% CO)}{.264(\% N_2) - [\% O_2 - .5(\% CO)]} \times 100$$

Refer to Appendix in Manual for derivations. Will not derive in class. Page D-1

C. Correcting a concentration to 50% excess air.

1. Between 1920-1940 many coal combustion sources operated at about 50% excess air. Today most sources operate at much lower excess air.

2. Excess air, $\% CO_2$, $\% O_2$ corrections used to correct for dilution of the flue gas. Note that a concentration can be reduced by dilution and a source could pass a concentration standard by doing so. These corrections bring emissions to a common referent, accounting for such dilution.

3. 50% excess air correction

L11-4

$$\bar{C}_{s_{50}} = \frac{\bar{C}_s (100 + \% \text{ EA})}{150}$$

4. 50% excess air correction from Orsat data

L11-5

$$\bar{C}_{s_{50}} = \frac{\overline{C_s}}{1 - \left[\frac{1.5(\% O_2) - .133(\% N_2) - .75(\% CO)}{21}\right]}$$

5. The equations are derived in Appendix of the manual. They are not equivalent expressions. In fact, both functions are not good functions and are not continuous. They will give different values for arbitrary values of $\% O_2$, $\% N_2$, and $\% CO$, but are almost identical combustion sources.

III. Correcting to 12%CO_2 — L11-6

A. Used in NSPS for municipal incinerators and by some states for some other sources.

B. $\bar{C}_{s_{12}} = \bar{C}_s \dfrac{12}{\%CO_2}$

C. The correction may cause a significant error in the reported emission rate, due to errors in determining %CO_2 by Orsat. One collaborative test contracted by EPA had a between test team deviation of concentration value of ∿ 15%. When corrections were made to 12%CO_2, deviation jumped to almost 25%.

IV. Correcting concentration to 6% oxygen — L11-7

1. Some standards are written in terms of an oxygen correction instead of a CO_2 correction

2. $\bar{C}_{s_{6\%O_2}} = \dfrac{\bar{C}_s\ [20.9 - 6.0]}{20.9 - \%O_2}$

3. Some standards may be corrected to 3%O_2 instead of 6%. Change 6 to 3 in this case. 20.9 is the % O_2 in air.

V. Practice in performing concentration corrections.

Page 100 Workbook

A. Perform calculations page 100 of workbook - example given.

Allow 30 minutes for problem. Have students take a break after they have finished.

B. Answers - Problem I in workbook

Fill in answers in Table after most students have finished first problem. Help those who are having difficulty.

		Orsat Analysis								$C_{s_{50}}$	
Test Number	% EA	%CO_2	%O_2	%CO	%N_2	Q_s DSCF/min.	PMR gr./min.	C_s gr./DSCF	$C_{s_{12}}$	% EA	From Raw Orsat Data
1A	10	13.3	2.2	0	84.3	14,300	10,000	.699	.631	.513	.507
1B	46.9	9.7	7.1	0.2	83.0	19,400	10,000	.515	.637	.505	.502

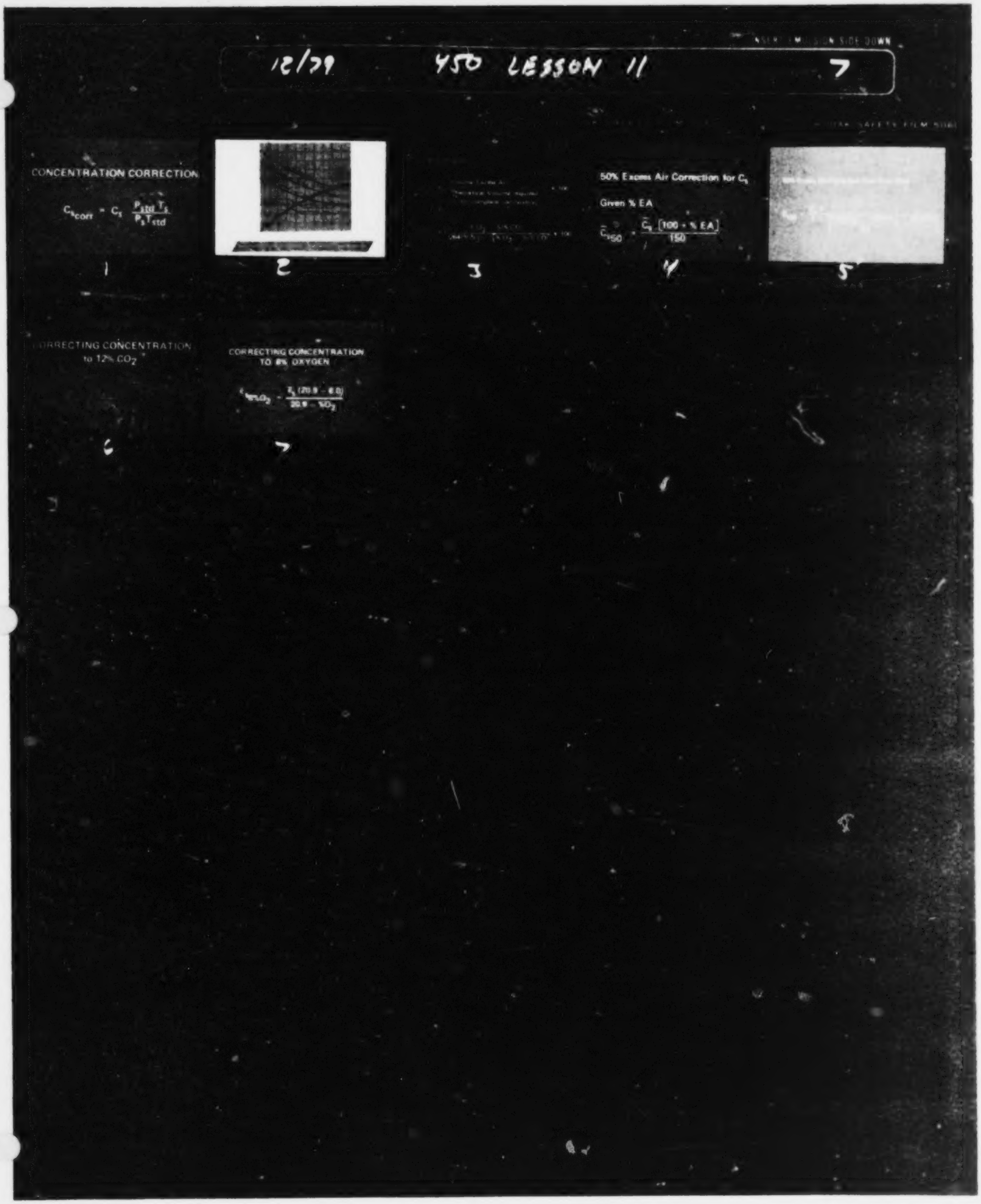
C. Answers - Problem II in workbook

Fill in answers in table (on chalkboard or overhead) after most students have finished. Let the others work until they get the correct answers.

Test Number	% EA	Orsat Analysis				Q_s DSCF/min.	PMR gr./min.	C_s gr./DSCF	$C_{s_{12}}$	$C_{s_{50}}$	
		$\%CO_2$	$\%O_2$	%CO	$\%N_2$					% EA	From Raw Orsat Data
2A	48.6	12.1	7.1	0.3	80.5	18,000	13,000	.722	.716	.715	.712
2B	100	9.1	10.6	0	80.3	24,000	13,000	.542	.714	.723	.721

D. Note the differences in answers — for coal fired boiler, answers all close. Why? Not so for oil fired boiler.

Refer to Fig. 11-2 coal combustion has the characteristics of 12% CO_2 corresponding to approximately 6% O_2 at 50% EA.
Oil does not.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12/79 450 LESSON 11 7

CONCENTRATION CORRECTION

$$C_{s_{corr}} = C_s \frac{P_{std} T_s}{P_s T_{std}}$$

1

2

3

50% Excess Air Correction for C_s

Given % EA

$$\bar{C}_{s_{50}} = \frac{\bar{C}_s [100 + \% EA]}{150}$$

4

5

CORRECTING CONCENTRATION
to 12% CO_2

6

CORRECTING CONCENTRATION
TO 8% OXYGEN

$$C_{s_{8\%O_2}} = \frac{\bar{C}_s (20.9 - 8.0)}{20.9 - \%O_2}$$

7

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: LITERATURE SOURCES

COURSE: 450 Lecture 12
LESSON TIME: 30 minutes
PREPARED BY: DATE:
J. A. Jahnke 9/21/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To introduce the student to alternate sources of information on source sampling and environmental control.

Lesson Objectives:

The student will be able to:

1. Recall at least three types of sources from which information on source sampling methodology may be found (books, periodicals, newsletters, EPA publications).
2. List the most important periodicals and professional organizations that transmit source sampling information.
3. Tell how to receive assistance in obtaining EPA publications and computerized literature searches.

Student Prerequisite Skills:

None

Level of Instruction:

Basic

Intended Student Professional Background:

Individual involved in air pollution control programs.

Support Materials and Equipment:

1. Course manual-Appendix B
2. Slide projector
3. Examples of literature - periodicals, books, etc., on air pollution control.
4. Brochure: "Need Air Pollution Information?"
   EPA office of Library Services

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Special Instructions:

This lecture is easy and light-hearted. It provides a breather in the morning, but is greatly appreciated by the students, particularly the industrial people.

References:

None

CONTENT OUTLINE

Course: 450 Lecture 12
Lecture Title: LITERATURE SOURCES

Page 1 *of* 3

NOTES

I. Books on Air Pollution Control, Sources, and Engineering — L12-1

A. Fundamentals of Air Pollution - Williamson Good
Introductory Text

B. Industrial Source Sampling - Brenchley, Turley, Yarmac
Written by 3 people who attended this course. Book now dated, but may have some good reference material

C. Air Pollution - Stern
5 volumes - review articles on all aspects of air pollution. Good reference

D. Chemical Engineer's Handbook - Perry
Good reference for practicing engineers

E. Source Testing for Air Pollution Control - Cooper and Rossano
Professional type approach to source sampling - now dated, but has useful information

F. AP-40 Air Pollution Engineering Manual
Basic Reference for Agency People -
Beg, borrow or steal.

G. Others

II. Periodicals — L12-2

A. Journal of the Air Pollution Control Association

1. Very important -refereed articles

2. Ask how many students belong to APCA

3. Others should be encouraged to join APCA if they are serious about their professional work

B. Environmental Science and Technology

1. ACS publication

2. Refereed articles

3. Articles on all areas of environmental control

C. Stack Sampling News

   1. Sometimes has tips and techniques on source sampling

   2. Contains announcements, etc.

   3. Articles are unrefereed

D. Pollution Engineering

   1. Freebee

   2. Articles on all areas of pollution

E. Staub Rheinhaltung der Luft

   1. Very important for articles on particulate control

   2. Unfortunately - in German - "staub" means "dust" - comes out 1 year later in English translation

F. Others: Power, TAPPI, Chemical Engineering, etc.

III. EPA Publications L12-3

A. Many publications available - obtain through NTIS or EPA library

   EPA Cumulative Bibliography 1970-1976 Parts 1 and 2 PB-265-920 and EPA Publications Bibliography Quarterly Abstracts Bulletin NTIS UB/D/042-01, 02, 03, etc., available from NTIS.

B. Note brochure "Need Air Pollution Information?", and services available from EPA library

C. Mention Federal Register and Code of Federal Regulations - their importance and the distinction between them.

IV. Newsletters L12-4

A. Quick communication on a daily or weekly basis

B. Expensive, but purchased by most libraries

   1. Environmental Reporter

   2. Air/Water Pollution Report

   3. Current contents

   4. IERL Report Abstracts

      NO_x Control Review

      FGD Control Review, etc.

V. Other Periodicals on Environmental Topics L12-5

A. Clean Air

B. Environment

C. Combustion

D. etc. → Make your own list

VI. Freebees L12-6

A. For people who like to get something in the mail

B. Industrial Research, American Laboratory, Laser Focus, etc.

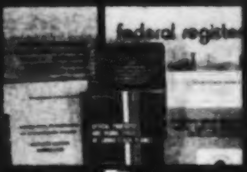
C. Pollution Equipment News

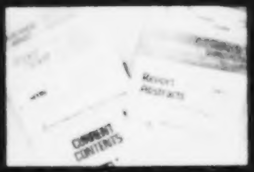
12/79 450 LESSON 12 8

air pollution

STACK SAMPLING NEWS
Air Pollution Control

2


federal register


Report Abstracts
CURRENT CONTENTS

Combustion
CHEMICAL ENGINEERING
Power

R/D
Optical Spectra
INDUSTRIAL RESEARCH

6

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: THE F-FACTOR METHOD

COURSE: 450 Lecture 13
LESSON TIME: 1 hour
PREPARED BY: DATE:
J. A. Jahnke 9/25/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To introduce the student to the concept of the F-Factor Method. To show two methods of performing the emission rate calculation and various techniques that can be performed with F-factors.

Lesson Objectives:

The student will be able to:

1. Define the F-factor used in EPA Methd 5 calculations
2. Discuss how the F-factor can give a value for the emission rate
3. Describe the requirements for using the F-factor in the EPA Method 5 test for new FFFSGs.
4. Recall alternate F-factor methods
5. Use F-factors for cross-checking Orsat and combustion data.

Student Prerequisite Skills:

Ability to multiply and divide

Level of Instruction:

College undergraduate science and math

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. Course workbook
2. Course manual
3. Slide projector

Special Instructions:

Not many students realize the importance of the F_d factor in the NSPS requirements for performing Method 5. Stress should be placed on this calculation method.

References:

October 6, 1975   40FR46250

CONTENT OUTLINE

AIR POLLUTION TRAINING INSTITUTE

Course: 450 Lecture 13

Lecture Title: THE F-FACTOR METHOD

Page 1 *of* 4

NOTES

I. Emission in terms of $lbs/10^6 Btu$ Heat Input

Page 108 Workbook

A. Previously expressed emissions in terms of

Write equation on board

$$E = \frac{pmr_s}{Q_H} = \frac{\bar{C}_s Q_s}{Q_H} = \frac{\frac{lbs}{\cancel{ft^3}} \; \frac{\cancel{ft^3}}{\cancel{hr}}}{10^6 Btu/\cancel{hr}}$$

$$= \frac{lbs}{10^6 \ Btu}$$

Note: Did this the first day, but most people in class have forgotten it by now

B. Problems:

1. Uncertainty in Q_H. What is Q_H?

   (Fuel feed rate) x (fuel heating value)

   Does EPA have a standarized fuel truck to check fuel feed meters? No. - have uncertainty here that can't check.

2. Too many variables in the equation for continuous monitoring applications.

II. F-Factor Method

A. Alternate Approach

write on board

$$E = \bar{C}_s F \begin{pmatrix} \text{dilution} \\ \text{correction} \\ \text{term} \end{pmatrix}$$

B. Definition of the F_d factor

L13-1

1. $$F_d = \frac{\text{volume of theoretical dry combustion products/lb}}{\text{heating value of fuel combusted } (10^6 \text{ Btu/lb})}$$

   $$= \frac{ft^3}{10^6 Btu}$$

   dimensionally, then

2. the emission rate from A, is then

$$E = \frac{\cancel{ft^3}}{10^6\ Btu} \quad \frac{lbs}{\cancel{ft^3}} = \frac{lbs}{10^6\ Btu}$$

dilution correction term is dimensionless

3. F-factors are relatively constant values for specific categories of fuels.

C. F_d factor method

L13-2

1. $E = \overline{C_s}\ F_d \left[\frac{20.9}{20.9 - \%O_2}\right]$

uses $\%O_2$ for dilution correction.

2. This is the equation must use in EPA Method 5.

3. Examples of F-factors

L13-3

Note more extensive list in manual - numbers in parentheses, give % deviation from the mean of data sets for which the F-factors were calculated.

Turn to page 9-11of manual.

Point out the small deviations.

4. EPA Method 5 and the F_d factor method

Required to use this calculation method. Also, required to perform oxygen traverse while doing Method 5 test. Note boxes - not too many students realize this. Draw sample into bag and analyze by Orsat or using continuous oxygen monitor if approved by administrator. Suggest follow procedures by Mitchell and Midgett - have two analysis agree to within .3%.

Turn to page 9-12 of manual.

Refer to page 9-15 of manual.

D. F_c factor method

L13-4

1. $F_c = \frac{\text{volume of theoretical } CO_2 \text{ generated by combustion/lb}}{\text{heating value of fuel combusted } (10^6\ Btu/lb)}$

This and following methods may be gone through quickly. They are important for continuous monitoring, but not for method 5 - Students, however, should know that they exist

2. the F_c factor method

$$E = \overline{C_s}\ F_c \left(\frac{100}{\%CO_2}\right)$$

L13-5

CONTENT OUTLINE

AIR POLLUTION TRAINING INSTITUTE

Course: 450 Lecture 13
Lecture Title: THE F-FACTOR METHOD

Page 3 *of* 4

NOTES

E. Using F_d factor to calculate E from data given on a wet basis

L13-6

Define $O_{2(w)}$ - Oxygen concentration on a wet basis

$$E = C_{ws} F_d \left[\frac{20.9}{20.9(1-B_{ws}) - \%O_{2(w)}} \right]$$

B_{ws} = fractional moisture content of stack gas

F. the wet F factor method F_w

L13-7

$$E = \overline{C}_{ws} \, F_w \left[\frac{20.9}{20.9(1-B_{wa}) - \%O_{2(w)}} \right]$$

where B_{wa} = fractional moisture content in air

Method used in continuous monitoring applications. B_{wa} can be determined by several methods.

G. Use of f-factors for cross checks

L13-8

1.

$$F_{d(calc)} = \frac{Q_{sd}}{Q_H} \left(\frac{20.9 - \%O_2}{20.9} \right)$$

Stoichiometric combustion check. If have all of data, a useful calculation to do. If F_d (calc) differs appreciably from tabulated values, have a problem either in Q_{sd}, Q_H, or $\%O_2$. Many people use this method to check their data.

2. Alternate expression

$$F_w(calc) = \frac{Q_{ws}}{Q_H} \left[\frac{20.9(1-B_{wa}) - \%O_{2(w)}}{20.9} \right]$$

3. Alternate expression

$$F_{c(calc)} = \frac{Q_{ws}}{Q_H} \left(\frac{\%CO_{2(w)}}{100} \right)$$

H. F_o factor — L13-9

1. Great help in checking Orsat data

$$F_o = \frac{20.9\ F_d}{100F_c}$$

$$F_o = \frac{20.9 - \%\ O_{2(d)}}{\%CO_{2(d)}}$$

2. If value not within 3 → 5% of that tabulated, have a problem with the Orsat data

I. Correcting for incomplete combustion — L13-10

1. F-factor method assumes complete combustion of fuel

2. Can make corrections, but normally CO levels are on ppm levels and do not greatly affect values

$$(\%\ CO_2)_{adj} = \%\ CO_2 + \%\ CO$$

$$(\%\ O_2)_{adj} = \%\ O_2 - .5(\%CO)$$

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12/79 450 LESSON 13 FILE NO 9

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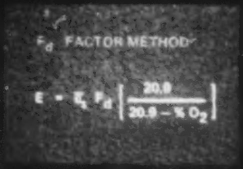

F_d FACTOR METHOD

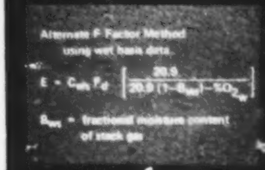
$$E = C_s F_d \left[\frac{20.9}{20.9 - \%\,O_2} \right]$$

2

3

4

5


Alternate F Factor Method using wet basis data

$$E = C_{ws} F_d \left[\frac{20.9}{20.9\,(1 - B_{ws}) - \%O_{2_{ws}}} \right]$$

B_{ws} = fractional moisture content of stack gas

6

Wet F Factor Method

F_w

7

8

9

Correcting for [illegible]

$(\%\,CO_2)_{adj}$

$(\%\,O_2)_{adj}$

10

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LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: CALCULATIONS REVIEW; CLEAN-UP PROCEDURES FOR THE RM5TEST - CALCULATIONS AND PRE-TEST REVIEW - DISCUSSION OF LABORATORY RESULTS

COURSE: 450 Lecture 14
LESSON TIME: 1 hour 45 minutes
PREPARED BY: Giuseppe J. Aldina **DATE:** 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To present clean-up procedures for the RM5 sampling system; review source test calculations and be sure all students can perform these; discussion the results of the source test as an introduction to the Error Analysis lecture.

Lesson Objectives:

The student should be able to:

1. List the clean-up procedures for the RM5 sampling train
2. Make all calculations for an RM5 stack test
3. Distinguish the difference between sampling precision and sampling accuracy
4. Answer all questions on the pre-test

Prerequisite Skills:

None

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

General Science

14

Support Materials:

1. Manual page 5-12
2. Workbook page 113
3. Programmed calculation sheet
4. Pre-test and answer key

Special Instructions:

Lecture is followed easily in the manual and workbook

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References:

None

We shall start this lesson by reviewing the pre-test since the laboratory did not allow time for a complete clean-up procedure of the RM5 sampling train. We will go through the flow chart in the manual on the clean-up procedures to be sure everyone can do this. We will then go through the calculations for the RM5 test and compare test results.

CONTENT OUTLINE

Page 1 *of* 1

NOTES

Course: 450 Lecture 14
Lecture Title: CALCULATIONS REVIEW;
CLEAN-UP PROCEDURES FOR RM5 TEST
CALCULATIONS AND PRE-TEST REVIEW
DISCUSSION OF LABORATORY RESULTS

I. Review Pre-test

II. RM5 Clean-up procedures - discuss procedures as given on page 5-12 of manual.

III. Calculations review

- A. Ask class for any questions on the calculations
- B. Go through calculations on programmed calculation sheet

IV. Class laboratory results - using page 113 of the workbook ask laboratory groups to give values they calculated.

- A. Generally
  1. Groups will get similar
     - a. Velocity data
     - b. Volumetric flowrate data
  2. Some groups will be out of isokinetic limit 90-110%
  3. Pollutant mass rate data and concentration data will vary but still be comparable
- B. Point out the similiarities and discrepancies in the laboratory results
- C. Introduce ERROR analysis topic

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: ERROR ANALYSIS

COURSE: 450 Lecture 15
LESSON TIME: 30 minutes
PREPARED BY: J. A. Jahnke
DATE: 9/22/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To provide the student with an understanding of the distinctions between error and precision and to review the types of error that can occur in source sampling.

Lesson Objectives:

1. The student will be able to explain the difference between precision and accuracy.
2. The student will be able to list and decribe three categories of error. (systematic, random, illegitimate)
3. The student will be able to discuss the relative precision of EPA reference methods 2-5.
4. The student will be able to use the concepts of this lecture and not missapply the terminology in discussions of source sampling results.

Student Prerequisite Skills:

None

Level of Instruction:

College entry level science

Support Materials and Equipment:

1. Course workbook
2. Course manual
3. Slide projector
4. Handout - reprint of article - Midgett, M. Rodney. "How EPA Validates NSPS Methodology." Environmental Science and Technology 11:655-659; July 1977.

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Special Instructions:

None

References:

Handout - reprint of article - Midgett, M. Rodney. "How EPA Validates NSPS Methodology." Environmental Science and Technology 11:655-659; July 1977.

CONTENT OUTLINE

Course: 450 Lecture 15
Lecture Title: ERROR ANALYSIS

Page 1 of 2

NOTES

I. The true value — L15-1

A. True value is what is wanted. Impossible to know what this is in source sampling

B. Collaborative tests may be close to true value, but not certain. Can only talk about deviations

II. Difference between precision and accuracy — L15-2

A. Precision refers to reproducibility

Accuracy refers to correctness — closeness to true value

B. Bull's eye

1. Closely spaced shot give estimate of good precision, but if any from bull's eyes, have poor accuracy — L15-2

2. Shot near bull's eye means good accuracy, but can have good or poor precision

3. The 3 method 5 tests give only an estimate of precision — tells nothing of accuracy. One value is no more valid than another if each test was done the same — Stress

III. Classification of errors — L15-3

A. Errors can arise from three basic reasons

1. Can be systematic — calibration problem, error in adjustment, consistent error in reading, etc. — may be corrected in some instances

2. Random errors — errors resulting from fluctuation, chance. Cannot remove. Idea is to eliminate all errors except random errors and keep these at a minimum.

3. Illegitimate errors — blunders, things which should not happen. Dropping the filter, leaks, misreading a dry gas meter, etc.

B. Emphasize that it is hard to remove all errors. Difficult to get estimate of error of test. %I does not give this. Average of three tests only gives an estimate of the precision, not the accuracy of the test.

Errors can affect both precision and accuracy.

IV. Estimates of prescision for EPA reference methods

A. Refer to paper by R. Midgett-
11, #7, (1977) p.657 Table 2 - Within laboratory deviation of the reference methods

1. Method 2 - 3.9%
2. Method 5 - 10.4%
3. Method 6 - 4.0%
4. Method 7 - 6.6%

B. Between laboratory deviation

1. Method 2 - 5.0
2. Method 5 - 12.1
3. Method 6 - 5.8
4. Method 7 9.5

C. Note: Estimates are for precision, not accuracy. Discuss results of laboratory in terms of the above concepts.

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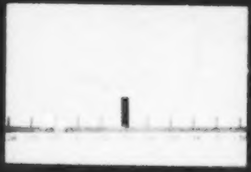
12/79 ISD LESSON 15 .10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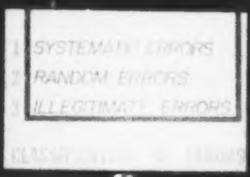
PRECISION AND ACCURACY

2


1. SYSTEMATIC ERRORS
2. RANDOM ERRORS
3. ILLEGITIMATE ERRORS

CLASSIFICATION OF ERRORS

3

4

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LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: SOURCE SAMPLING QUALITY ASSURANCE AND SAFETY ON THE SAMPLING SITE

COURSE: 450 Lecture 16
LESSON TIME: 1 hour 20 minutes
PREPARED BY: DATE:
Giuseppe J. Aldina 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

Stimulate students to be aware of all aspects of the sampling procedure which effect the quality of the data and the safety of the sampler at the sampling site.

Lesson Objectives:

The student should be able to:

1. Recall the important aspects of an accident analysis program
2. List the 10 causes of accidents
3. List some personal safety equipment for a source sampler
4. List the important items necessary to assure good quality test data

Prerequisite Skills:

The course up to this point

Level of Instruction:

College science

Intended Student Professional Background:

General Science

Support Materials:

1. Blackboard and chalk or overhead projector and pens
2. Slide projector
3. Workbook - page 119
4. Manual - page 5-15

Special Instructions:

Let the students think up the quality assurance points with help from the instructor.

References

CRC Handbook of Laboratory Safety

This lecture is devoted to the safety of sampling personnel at the site and points of quality assurance for source sampling using RM5. The major aspects of an accident analysis program and the 10 common causes of accidents are presented. The class will then list the major points to evaluate in assuring good quality source test data for both the tester and observer.

AIR POLLUTION TRAINING INSTITUTE

CONTENT OUTLINE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Course: 450 Lecture 16
Lecture Title: SOURCE SAMPLING QUALITY ASSURANCE AND SAFETY ON THE SAMPLING SITE

Page 1 *of* 7

NOTES

I. Accident analysis

  A. Accidents are caused therefore they can be prevented

  B. The best system for preventing accidents is an accident analysis program

    1. Analyze all possible causes of an accident before it happens

    2. Take measures to eliminate possible causes of accidents

    3. Ask personnel working in the area for suggestions

    4. If an accident does occur

      a. Find out how it happened

      b. Ask the injured person(s) how it happened

      c. Ask the injured person(s) for suggestions on how to prevent a reoccurrence

II. Causes of accidents — L16-1

  A. Poor instructions

    1. Supervisory personnel must give adequate instructions for

      a. Job performance

      b. Safety requirements

    2. Supervisor should inspect job site for all applicable concerns and safety

      a. Before

      b. During and

      c. After the job

B. Poor planning

  1. The person-in-charge must properly plan and conduct the activity

  2. Experiment design and performance are extremely important for job success and safety

  3. Specifically for stack test - adequate manpower to do the job

C. Improper design - the experiment must be designed with proper equipment, layout, and construction for completion of the job

D. Proper equipment not provided

  1. Safety equipment must be available

  2. Proper tools and other equipment must be on hand - Jury rigging is poor practice

E. Failure to follow instructions

  1. All personnel must follow safety rules

  2. Explicit instructions must be given to all personnel involved at the job

F. Neglect or improper use of equipment

  1. All personnel must use the proper safety equipment

  2. Do not try to use a piece of equipment for a purpose for which it was not intended (i.e. do not try to drill a 1/2" hole with a 1/4" drill bit)

G. Faulty equipment — poorly maintained equipment is inexcusable

H. Untrained personnel

  1. All personnel should have adequate training before their participation at the job site

  2. Trainees should be closely supervised

I. Uncooperative personnel

1. Persons in poor physical condition or poor mental attitude should be given different assignments

2. This applys to attitudes about co-workers, supervisor, the job, or working conditions

J. Unpreditable outside agents

1. Agents outside the control of the sampling team

2. Can mean anything such as bad weather or a stinging insect which may startle someone and cause an accident

III. Personal safety equipment

Ask the class to describe these. It is more useful than a simple listing.

A. Hard hat

B. Safety glasses

C. Safety shoes

D. Respirators

E. First aid kit

F. Gloves

1. Leather work gloves

2. Heat protective gloves

G. Proper clothing

1. No shorts

2. Longsleeve shirts

3. Appropriate for weather conditions

H. Plenty of drinking water and some snack food to prevent fatigue. No salt tablets - They are bad for you

I. Safety belts

Maintain the discussion as long as students make responses.

IV. Quality Assurance

A. Introduction

This lecture is to be held as an interactive student-teacher discussion session. Have the students contribute ideas towards the development of a QA program. List points on the board and have the students list in their workbooks

Ask students what would make good quality assurance checks for a stack test. They will, by this point, be able to list the items given.

B. Equipment Calibrations
  1. Nozzle
  2. Pitot tube
  3. Heaters - probe and filter
  4. Dry gas meter
  5. Orifice meter

C. Observations that can be made by the agency observer at the sampling site.
  1. Leak checks - before and after sampling
  2. Reference Method 1 requirements
  3. Probe alignment
  4. Precise meter console operation - data recording
  5. Reference Method 3 requirements
  6. Overall competancy of sampling team
     a. Experience
     b. Education
     c. Professionalims
  7. Coordination with source operation
  8. Parameter checks on stack gas
     a. Stack gas temperature
     b. Preliminary traverse for cyclonic gas flow and Δp
     c. Moisture content of the gas
  9. Adherence to reference method procedures
  10. System vacuum

11. Sampling system temperatures
    a. Filter
    b. Impingers
    c. Dry gas meter
12. ΔH calculation from Δp

C. Parameters the control agency observer should record

1. Test start and end times
2. "S" type pitot tube C_p
3. Nozzle diameter
4. Leak rate of the train
    a. Initial leak rate
    b. Leak rate anytime train is disassembled
    c. Post-test leak rate
5. Dry gas meter volume
6. K factor for nomograph or calculator
7. Average square root of the Δp readings
8. Average ΔH
9. Volume of H_2O trapped in the sample train
10. Filter tare weights
11. Orsat data

D. Process operation data (as applicable)

1. Materials feed rate
2. Production rate
3. Fuel feed rate
4. Shift changes
5. Upsets

E. Analytical procedures

1. Clean-up techniques for the RM5 sample train
    a. Care taken
    b. Thoroughness of clean-up
    c. Careful labeling of all samples
    d. If sample to be shipped for analysis sample volume should be marked
2. Laboratory staff
    a. Bachelor degree chemist
    b. Certified technician
3. Sample analysis
    a. Sample solvent blank taken
    b. Sample dried at room temperature or heated to no more than filter temperature during sampling
    c. All data carefully recorded
4. Weighing and desicating
    a. Scale sensitivity within 0.5 mg
    b. Sensitivity checked routinely
    c. All tare weights carefully recorded
    d. Sample desicated 24 hours then weighed to nearest 0.5 mg
    e. Sample desicated and weighed at six hour intervals to constant weight ± 0.5 mg
5. Overall laboratory observations
    a. Cleanliness
    b. Order
    c. Equipment in good condition

All these observations are important in good quality assurance assessment for the RM5 test.

We have covered safety at the source with emphasis on accident analysis and preventing the most common causes of accidents. We have, also, listed the major items for good quality assurance of a RM5 test. This concludes this lecture.

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: PARTICLE SIZING USING A CASCADE IMPACTOR

COURSE: 450 - Lecture 17
LESSON TIME: 1 hour
PREPARED BY: DATE:
Giuseppe J. Aldina 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To familiarize students with the basic principles of inertial particle sizing techniques and the use of in-stack cascade impactors for gathering particle size data.

Lesson Objectives:

The student should be able to:

1. Describe the equation of continuity for a flowing ideal fluid
2. List several particle properties and give the most important property of particles with regard to sizing devices.
3. Define effective particle size
4. Define particle aerodynamic diameter
5. Describe the relationship between particle diameter and its physical properties
6. List several methods of determining particle diameter other than inertial sizing
7. Recognize the importance of particle size data
8. Describe the operation of a cascade impactor
9. Define the D_{50} for an impactor collection stage
10. Describe the sampling procedures used for an in-stack cascade impactor

Prerequisite Skills:

The course to this point.

Level of Instruction:

College undergraduate science

17

Preceding page blank

Intended Student Profession Background:

General Science

Support Materials and Equipment:

1. Manual page 9-16
2. Workbook page 123
3. Slide projector
4. Cascade impactor

Special Instructions:

None

References:

Laple, C. E., Fluid and Particle Mechanics, University of Delaware; Newark, Delaware; 1956

Particle sizing is becoming increasingly important in source sampling. The high cost of particulate control equipment and tighter regulations have put great pressure on equipment designers. The design of particulate control equipment is very much dependent upon good particle size data. A manufacturer can develop better equipment when the actual size distribution of particles in the gas stream is known. For this reason in-stack particle sizing has received increased interest.

Particle size data is also important in developing new instrumentation for source monitoring. In this course we shall deal with particle size as related to plume opacity measurements. Research is also being conducted on instruments that continuously measure mass emissions from a source. The optical techniques used for these instruments require valid particle size data.

AIR POLLUTION TRAINING INSTITUTE

CONTENT OUTLINE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NOTES

Course: 450 Lecture 17

Lecture Title: Particle Sizing Using a Cascade Impactor

I. Particle properties

A. A particle has several important properties

1. Mass

2. Dimension

3. Chemical composition

4. Aerodynamic properties

5. Optical properties

B. The primary distinguishing characteristic of any particle is particle size

II. Size determination

A. Several methods for determining particle size

1. Microscopic

a. Taking a measurement of the particle dimensions

1) Martin's Diameter — measures the diameter across the middle of the particle

2) Feret's Diameter — measures the longest linear dimension of the particle

3) Equivalent projected area — compares an irregular particle's diameter to a sphere that seems to approximate the particle size

b. These give precise particle dimensions as viewed under the microscope

c. There are several drawbacks

1) The procedure is expensive when done often enough for a statistically representative sample

2) Taking samples can cause fracturing and agglomeration of particles

3) Always an uncertainty of the microscopic data as related to actual in-stack particle size distribution

2. Sedimentation and Elutriation

   a. Again requires an extracted sample with the uncertainties involved in taking the sample from the stack

   b. These require very large samples for obtaining sizing data

3. Out of stack inertial techniques

   a. Bacho sizer is the most commonly used.

   b. Many improvements have been made in these techniques

   c. An out of stack analysis always carries the problem of relating results to actual in-stack particle distribution

B. In-stack particle sizing when properly conducted provides the most useful, valid data. We will concentrate on this method.

C. All techniques used for particle sizing incorporate empirical relationships and theoretical principles to describe particle size

   1. Size is not really determined

   2. These techniques assign the particle an "effective size" based on observations of the particle properties

D. Any technique used for particle size analysis will yield unique data

   1. Data gathered by different techniques does not necessarily agree

   2. Data gathered by different designs of instrumentation using the same principle may not agree

   3. These uncertainties require that

      a. Careful consideration be given to objectives for the experiment

      b. Cost for the analysis be weighed in conjunction with the use of the data.

III. Particle physical properties

   A. Particle size generally refers to an "effective size"

1. Described as equivalent or effect diameter

2. Great deal of information has been gathered on spheres of unit density in dry air.

B. Particle sizing techniques seek to define particle size in terms equivalent to these spheres

1. The most commonly used term is particle diameter

2. Assuming a particle's physical properties will be equivalent to those of a sphere of the same diameter

3. And that a physical property is proportional to some power of the diameter

$(d)Q = \propto d^N$

d = diameter
∝ = shape factor
N = a number
Q = physical property

4. Then particle behavior may be predicted for a given set of conditions

5. This is an essential factor in designing control equipment

We can see the importance of particle size data from this discussion. Now let us move to learning how an in-stack cascade impactor works to give particle size data.

IV. Particle Motion

A. The most useful particle sizing methods for stack sampling purposes define particle size as an "aerodynamic diameter"

1. Allows prediction of particle aerodynamic properties

2. These are extremely important in designing control equipment

a. Electrostatic precipitators

b. High energy scrubbers

B. Fluid dynamics and Stokes Law — These principles will aid in understanding the operation of a cascade impactor

1. The tube of fluid flow

Slide L17-1

a. The fluid is ideal - incompressible and non viscous

b. Flowing from P to Q

c. The mass flux at P is described

$$\frac{dm}{dt} = \rho_1 A_1 v_1$$ L17-2

as t → 0

$$\Delta m_1 = \rho_1 A_1 v_1$$

d. We can describe the mass flux at Q as L17-3

$$\frac{dm_2}{dt} = \rho_2 A_2 v_2$$

as t → 0

$$\Delta m_2 = \rho_2 A_2 v_2$$

e. We stated before that our fluid is incompressible and non-viscous. This means ρ does not change and Δm at both points is equal.

1) $$\frac{dm_1}{dt} = \frac{dm_2}{dt}$$

as t → 0

$$\Delta m_1 = \Delta m_2$$

2) $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

3) $A_1 v_1 = A_2 v_2$

f. We see that velocity is changing to get the same mass flux at both points

h. If we go from Q to P, what happens?

v_1 is greater than v_2

2. Fluid flow around a submerged particle (The slide shows fluid streamlines around the particle. Show the students how the velocity of the fluid changes from point I, II and III) L17-4

a. At Point I we have fluid moving toward the particle

1) Fluid pressure = P_T

2) Velocity = v_I

b. At Point II

1) The fluid streamlines come closer together

2) By the equation of continuity we know that for an ideal fluid the fluid velocity must increase to maintain the same mass flux

3) The energy to increase velocity must come from somewhere. Where?

4) The needed energy is coming from the pressure in the system

5) So P_T decreases at Point II and velocity increases

L17-5

6) This can be proven from Bernoulli's Theorem.

(The intention here is to go over the relationships shown at the bottom of the slide — not a complete mathematical proof)

c. At Point III in our ideal fluid P_T would return to the value at Point I and V_{II} would return to V_I.

d. In a real system we would not have a complete return to the original values at Point I

It is not necessary to get too deeply into the fluid dynamics of this system

1) Some energy would be disipated as heat because of friction around the particle

2) The pressure at Point III would not return to P_T (It would be some distance down stream)

3) The net effect would be the lower pressure fluid at Point II being pushed back by the higher pressure fluid behind Point III

4) This creates vortices which create a net pressure drag on the particle

3. Stokes Law — Gravitational force versus frictional force

a. The motion of our submerged particle will be determined by the forces acting upon it

b. A particle will remain at rest in relation to the fluid until acted upon by some external force — Newton's first law

c. Newton's 2nd Law — acceleration caused by a force acting upon a body is proportional and parallel to the resultant of that force and is inversely proportional to the mass of the body

d. Newton's 3rd Law of Motion — a body exerting a force on another body encounters an equal and opposite force

e. Stokes applied these laws to the motion of a particle submerged in a fluid and proved mathematically that a body falling in a fluid is

1) accelerated by gravity F_g

2) acted upon by an equal and oppositely directed frictional force F_R

3) that when $F_g = F_R$ the net acceleration on the particle is zero

4) the particle therefore reached a terminal or settling velocity

5) the particle mass and its terminal velocity determined its ability to move through the fluid-overcome the fluid friction.

V. The cascade impactor

L17-6

A. These principles are used in the cascade impactor

B. The fluid velocity at each stage in the impactor is governed by the diameter of the stage orifice

C. Particles are accelerated through the orifice and reach a terminal velocity when the forces acting on it are equal

D. The particle then has a momentum proportional to its mass which may allow it to impact on to the collection stage

E. The particles are fractionated into various size ranges based upon orifice velocity and particle mass

1. This defines the aerodynamic diameter of the particle

a. An effect diameter based upon the assumption that large particles have more mass than small particles

b. Assumes uniform particle density

2. The aerodynamic diameter of the particle allows correlation of empirical data to the unknown particle size for prediction of its physical properties

F. This procedure yields useful data though there are some problems

1. Particles may not have uniform density so the size predicted by the impactor may not be accurate
2. Particles may bounce in the impactor and land on inappropriate stages
3. Particles may break on impacting a collection stage and be reentrained - biasing small size fractions
4. No collection stage will be 100% efficient in collecting particles for which it is designed

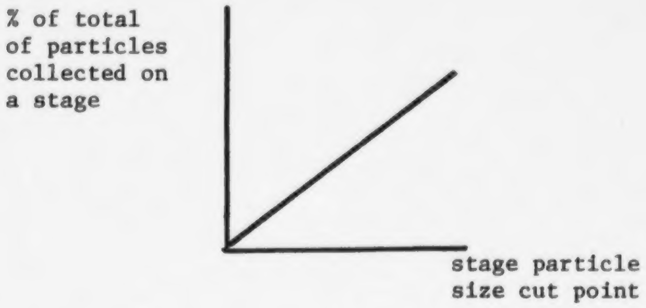
G. Collection stage efficiency

1. Impactors sold commercially are generally supplied with stage cut points developed from theoretical calculations
2. These are not necessarily valid
    a. Each impactor even within a given design may have different fractional characteristics for a collection stage
    b. Impactors should be accompanied by calibration data developed by the manufacturer using monodisperse aerosols to obtain actual fraction sizes for a stage.
    c. The most common experession of fraction size for a collection stage is the D_{50}
        1) The D_{50} is the particle size for which the stage has at least a 50% collection efficiency.
        2) This is usually called the cut point diameter

H. Data Presentation

1. The most common and useful presentation is a cumulative distribution plot on log-probability graph paper

2. The graph is plotted



which should show a straight line on log-probability paper

VI. Impactor Sampling Procedures

A. The standard sampling train can be used

1. This is the easiest way to do the sampling because you can operate it just like RM5

2. The impactor is positioned at the probe end then a nozzle is attached to the impactor head

3. A pitot tube may or may not be necessary

a. It is usually easier to get the impactor into the sample point without the pitot tube

b. Though we have spent the entire course addressing isokinetic sampling we may not be doing this with an impactor since it loads up so quickly.

B. Non-isokinetic sampling

1. The sampling train is prepared as in RM5

2. The nomograph or calculator is used to determine the ΔH for the Δp in the duct

3. A preliminary test should be run to determine if isokinetic sampling is appropriate

a. The isokinetic flow rate through the impactor may be too high

b. If the flow rate is too high errors occur in the impactor

1) Scouring of collection stages

2) Reentrainment of particles

4. If the impactor does not show discrete clean particulate catches flow rate will have to be lowered

   a. This does bias the sample but not as much as scouring and reentrainment

   b. It will change stage cut points some

   c. These are uncertainties that are still being researched

C. Repetitions — it can require as many as 30 sample runs to get valid data

   1. 3 runs should be minimum

   2. 9 runs is probably a practical limit

Particle sizing is a complex endeavor. Cascade impactors give the most useful data for stack samplers but they are not perfect. Always assess the need and uses of the data before planning a program for sizing particles in a duct.

INSERT EMULSION SIDE DOWN

12/79 450 LESSON 17 12

TUBE OF FLUID FLOW

1

ass Flux at 1

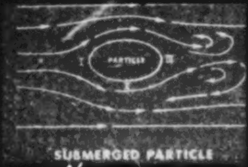
$$\frac{\Delta m_1}{\Delta t} = \rho_1 A_1 v_1$$

$$\Delta t \to 0 \quad \frac{dm_1}{dt} = \rho_1 A_1 v_1$$

2

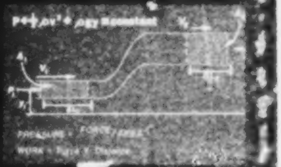
[illegible]

3



SUBMERGED PARTICLE

4



$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$

PRESSURE = FORCE/AREA

WORK = Force X Distance

5

INERTIAL
PARTICLE
COLLECTOR

6

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: TRANSMISSOMETERS

COURSE: 450 - Lecture 18
LESSON TIME: 1 hour 15 minutes
PREPARED BY: J. Jahnke DATE: 9/28/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

18

Lesson Goal:

To introduce the student to the field of continuous opacity monitoring using transmissometers. To show instrument design characteristics, typical installations, and the relationship of opacity to particulate mass measurements.

Lesson Objectives:

The student will be able to:

1. Define the terms opacity, transmittance, and transmissometer.
2. Express the relationship between opacity and transmittance.
3. Recognize the proper expression for optical density.
4. Discuss the EPA requirements for the design and performance of transmissometers placed on sources regulated by NSPS.
5. Define the meaning of photopic and give at least two reasons why light in the photopic region is to be used in transmissometer design.
6. Explain that optical density is proportional to grain loading and discuss the advantages and limitations of correlating optical density to grain loading.
7. List several uses of opacity monitors.

Student Prequisite Skills:

Some concept of logarithms and exponential functions (note: students do learn about logarithms in high school)

Level of Instruction:

College undergraduate physics

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. Course workbook
2. Course manual
3. Slide projector
4. Demonstration transmissometer, if available

Special Instructions:

This is the last lecture in the course. Some students may be restless by this time, eager to take the post-test and go home. The lecture should be given to the point, meeting the objectives, without elaborating on details.

References:

Federal Register - Vol. 40, No. 194, October 6, 1975. "Emission Monitoring."

CONTENT OUTLINE

Course: 450 Lecture 18
Lecture Title: Transmissometers

Page 1 *of* 4

NOTES

I. Definition of opacity

L18-1
Intro. Slide

A. Opacity is the percentage of visible light attenuated due to the absorption and scattering of light by particulate matter in the flue gas.

L18-2

B. Relationship between % opacity and % transmittance
% opacity = 100% - % transmittance

C. Opacity monitor = transmissometer.

Transmissometer stands for transmission meter.

Give example -
using overhead
projector - look at
beam of projector
0% opacity 100% T,
put a book in front
of your eyes
100% opacity 0% T

II. Single-pass transmissometer

L18-3

A. Light source, detector, blowers

B. Point out collimating lenses, fact that light source and detector are on opposite sides of lenses

C. Blowers used to keep optics clean

III. Double pass transmissometers

L18-4

A. Point out features

B. Note that lamp and detector are on same side of stack, allowing for simulated zero and calibration check.

C. Double pass systems more expensive than single pass systems, but more likely to meet EPA design and performance specifications.

IV. Commercially available transmissometers

L18-5a
L18-5b

A. Many vendors — single pass and double pass

B. Vendors of double pass transmissometers - Lear-Siegler, RAC, Contravez-Goertz, Esterline Angus, Dynatron, Data test, Anderson-2000.

C. Single pass — others on list

D. List changes frequently — not up to date, vendors go in and out of business.

V. Opacity monitor specifications

L18-6

A. Have two types of specifications for monitors required under NSPS and SIP's

1. Design specifications

2. Performance specifications

B. Design specifications

1. Spectral response must be in photopic region.

2. Angle of view and angle of projection limited to 5°.

3. Calibration error — limited to 3% opacity

4. Response time — 10 seconds maximum from 0 to 95% of Cal. value.
5. Must have facility for system zero and span check.

C. Performance Specification

1. To be performed with monitor placed on stack.

2. 24 hour zero drift $\leq$ 2% opacity

3. 24 hour calibration drift $\leq$ 2% opacity

VI. Photopic region — design specification L18-7

A. Photopic region--visible region of the spectrum 400-700nm corresponds to wavelengths the human eye is sensitive to. Might have correlations to Method 9.

B. Chosen since have H_2O and CO_2 interference in IR region. H_2O not a pollutant.

C. Smaller particles attenuate light better at shorter wavelengths. Hence the light wavelengths are limited to the photopic region. L18-9

VII. Angle of projection and angle of view

A. Angle of projector — Angle of the cone of light projected by the lamp. L18-10

B. Angle of view — Angle of the cone sensed by the detector

C. Limitation necessary, so they don't get contribution of light from outside volumes.

D. Most instruments meet or exceed these specifications.

VIII. Transmissometer siting

A. Transmissometers are to be placed at a point which will give a representative value for the opacity. L18-11

B. Must be placed in the plane of the bend

C. Should be in accessible location to allow good servicing of the instrument

IX. Relationship between emission opacity and monitor opacity L18-12

A. $O_1 = 1 - (1 - O_2)^{L_1/L_2}$

L_1 = emission outlet pathlength

L_2 = monitor pathlength

O_1 = emission opacity

O_2 = monitor opacity

B. Used to correlate opacity at stack exit with that seen across transmissometer pathlength.

C. Necessary in terms of regulation may or may not correlate with EPA Method 9 observation.

X. Transmissometer Applications L18-13

A. Installation to satisfy EPA continuous monitoring requirements - 40 CFR 60.

B. Installation for process performance data - maintenance and repair indicator, process improvement combustion efficiency. L18-14

C. Installation for control equipment operation - ESP tuning broken bag detector.

D. Correlation with particulate concentration

E. Maintenance of a continuous emission record.

XI. Correlation of opacity with particulate concentration L18-15

A. The Beer-Lambert-Bougert relationship

$1-O = T = e^{-naq\ell}$

T = transmittance

n = number of particles/unit volume

a = mean particle projected area

q = particle extinction coefficient

ℓ = effluent path-length

B. Optical density L18-16

1. $\text{O.D.} = \log_{10} \frac{1}{1 - \text{opacity}} = Kc\ell$

K = a constant
c = concentration
ℓ = pathlength

2. Optional density is a measure of the ability of an aerosol to attenuate light.

3. Optical density is proportional to both pathlength and particulate concentration, so long as the particle characteristics remain the same.

4. Can make correlation between EPA Method 5 and optical density — L18-17, L18-18, L18-19

   Examples: Lignite for boilers
   Cement kiln emissions
   Bituminous coal-fired boilers

XII. Examples of opacity monitoring installations

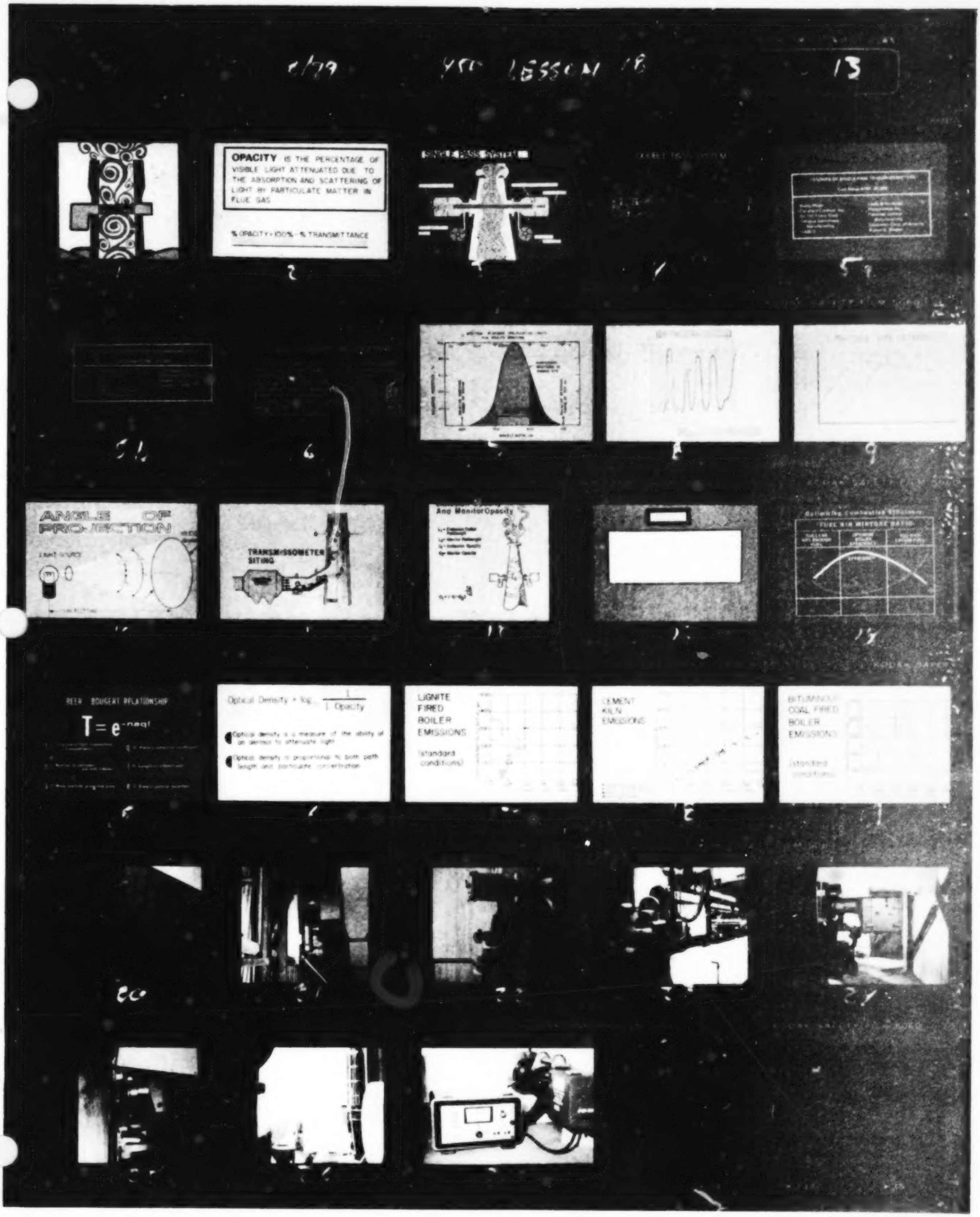
- A. Durag analyzer on power plant duct — L18-20
- B. Durag analyzer on power plant duct — L18-21
- C. Retro-reflector for Durag opacity monitor — L18-23
- D. Transmissometer and blower assembly on EPA stationary source simulator facility — L18-23
- E. Lear-Siegler Model #RM4 transmissometer on power plant stack — L18-24
- F. Lear-Siegler Model #RM4 retroreflector assembly on power plant stack — L18-25
- G. Protective shrouds on transmissometer located on stack — L18-26
- H. Portable transmissometer, Lear-Siegler RM41P on EPA stationary source simulator — L18-27

XIII. Course closing

- A. This is the last lecture in the course. Have the students take a break and then proceed with the post-test.
- B. Post-test

  Students need to achieve 70% on post-test before certificates will be awarded. Certificates will be mailed. Have answer sheet available so that students may check answers.
- C. Hand out course critiques. No student will receive certificate unless critique is returned.
- D. Collect post-test answer sheets and critiques.

8/79 YSC LESSON 18 13



OPACITY IS THE PERCENTAGE OF VISIBLE LIGHT ATTENUATED DUE TO THE ABSORPTION AND SCATTERING OF LIGHT BY PARTICULATE MATTER IN FLUE GAS

% OPACITY = 100% − % TRANSMITTANCE

BEER - BOUGERT RELATIONSHIP

$T = e^{-nagl}$

$\text{Optical Density} = \log_{10} \frac{1}{1 - \text{Opacity}}$

Optical density is a measure of the ability of an aerosol to attenuate light

Optical density is proportional to both path length and particulate concentration

LIGNITE FIRED BOILER EMISSIONS (standard conditions)

CEMENT KILN EMISSIONS

BITUMINOUS COAL FIRED BOILER EMISSIONS (standard conditions)

SINGLE PASS SYSTEM
DOUBLE PASS SYSTEM
ANGLE OF PROJECTION
LIGHT SOURCE
TRANSMISSOMETER SITING
And Monitor Opacity
Optimizing Combustion Efficiency
FUEL AIR MIXTURE RATIO
1
2
6
9
20

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: MONDAY LABORATORY INSTRUCTIONS

COURSE: 450 Laboratory 1
LESSON TIME: 2½ hours
PREPARED BY: Giuseppe J. Aldina
DATE: 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Topics: Laboratories

1. Reference Method 1
2. Pitot tube calibration
3. Wet bulb-dry bulb moisture estimate
4. Orifice meter calibration

Lesson Goal:

Give students hands-on experience with RM5 equipment and procedures.

Lesson Objectives:

1. Layout, diagram, and make all necessary decisions and calculations for RM1
2. Collect calibration data for an "S" type pitot tube and calculate C_p for legs A and B
3. Estimate moisture in the stack gas using the wet bulb-dry bulb technique
4. Calibrate the meter console orifice meter for a $\Delta H_@$ of 0.75 CFM at 29.92 in. Hg and $68\ ^{o}F$

Prerequisite Skills:

None

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. 450 Workbook
    - a. RM1 pages 20-23 ; Pre-survey 137-140
    - b. Pitot tube calibration pages 24-26
    - c. Wet bulb-dry bulb pages 27-32
    - d. Orifice meter calibration pages 33-36
2. Laboratory duct - see equipment list (Introductory section of this Guide)
3. Laboratory equipment - see equipment list (Introductory section of this Guide)
    - a. Meter consoles
    - b. Standard pitot tubes
    - c. Inclined manometers and ring stands
    - d. Assembled sampling probes with "S" type pitot and nozzle
    - e. Tubing
    - f. Thermometers
    - g. Cotton wicks and a beaker of H_2O
    - h. Stopwatches
    - i. Extension cords
    - j. Rulers
    - k. Tools
    - l. Duct tape
4. Calculators
5. Pencils

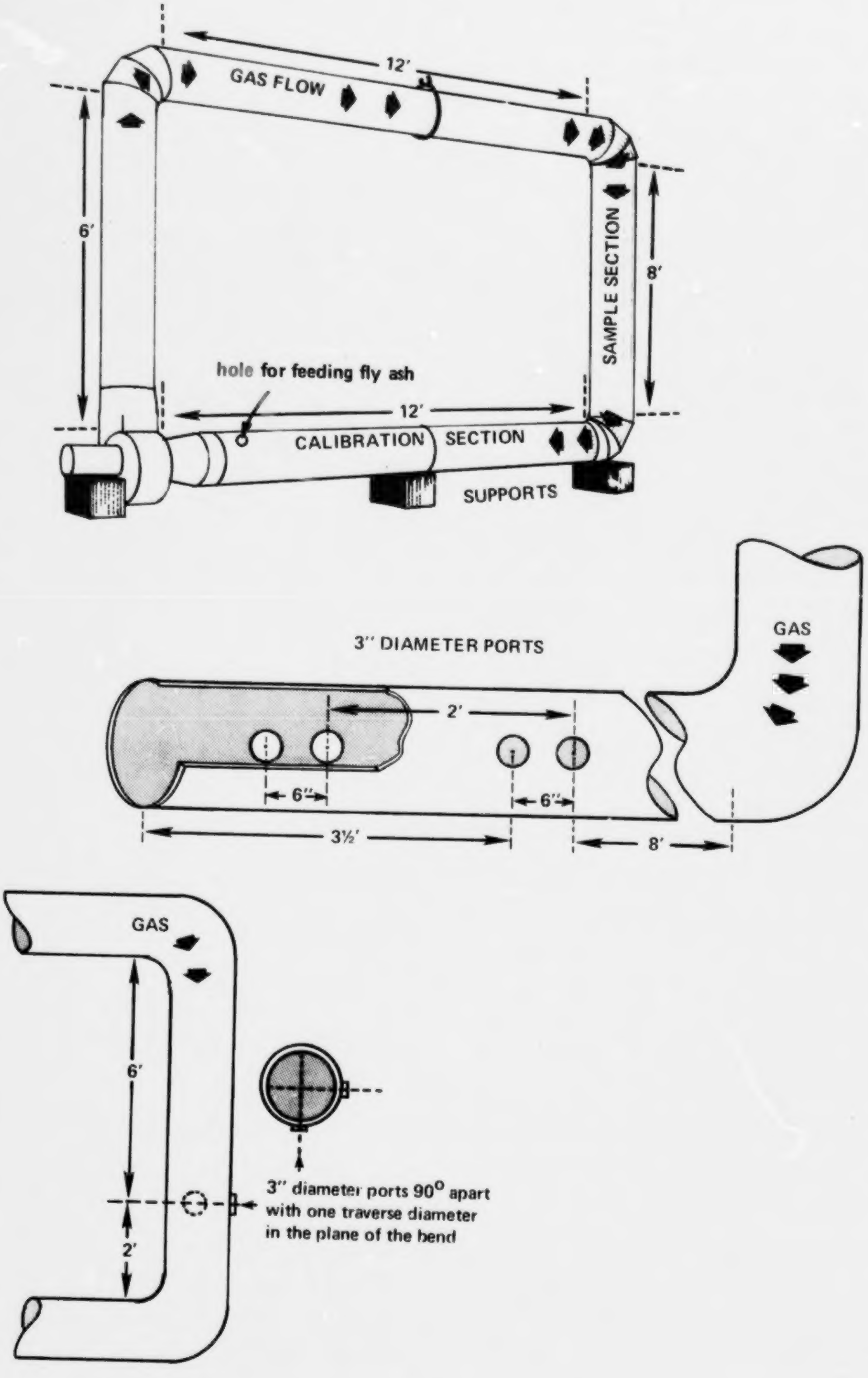

12'
GAS FLOW
6'
8'
SAMPLE SECTION
hole for feeding fly ash
12'
CALIBRATION SECTION
SUPPORTS
3" DIAMETER PORTS
GAS
2'
6"
6"
3½'
8'
GAS
6'
2'
3" diameter ports 90° apart
with one traverse diameter
in the plane of the bend

Figure 1. Laboratory Duct.

Special Instructions:

1. Assemble duct work before the laboratory is scheduled to begin
2. Seal all joints in the duct work with duct tape
3. Label all equipment with a group number
4. Put wicks on 2 thermometers
5. Arrange meter consoles on tables so there is plenty of room around the calibration duct
6. Plug equipment into as many different electrical lines as possible to prevent overloading circuit breakers
7. Be sure manometers have proper fluid levels
8. Provide space and platforms so manometers can be leveled on a stable surface
9. Support long duct sections: top sections from ceiling

References:

None

Instructor Preparations:

1. Read all the laboratory procedures and corresponding lectures
2. Check all equipment operations in advance
3. Arrange pitot tube experiments at horizontal ports
4. Arrange meter consoles with stopwatches so there is plenty of room around the duct
5. Using laboratory procedures check orifice meter calibrations. Record the data as reference. ΔH@ should be 1.5-2.1 in. H_2O
6. Determining the dry gas meter correction factor using a spirometer would be good practice, but it is not necessary for this laboratory exercise. Assume DGMCF = 1.0.
7. Note: When the DGMCF is known the laboratory orifice meter calibration is accurate. APTD - 0576 should be the procedure used by the student as a standard practice unless DGMCF is determined by spirometer

8. Divide the students into groups of 6 (unless the student/ equipment ratio will allow smaller groups) before class starts on Monday

9. Label each experiment so students can easily identify what exercise to read in the workbook

10. Heat and moisture can be added to the duct with a small propane torch and pyrex beaker with H_2O but it is not necessary

11. A schedule for each group at an experiment may be desirable, however, laboratory generally proceeds well without it. The schedule would diminish student anxiety about finishing the lab. At a stack test no schedule exists so it may be most beneficial to allow students to get a feel for the real times required at a test. They will prefer a structure but will undoubtedly not keep it

12. Post the barometric pressure (for the laboratory) for each lab in inches and millimeter of Hg

Instructions to the Students:

1. All students should read the laboratory exercises in the workbook first. (Generally they will not follow this direction so be prepared to answer many questions)

2. Be sure to perform all required experiments (many students will try to skip RM1 or the wet bulb-dry bulb)

3. Approach RM1 as if no ports were cut into the duct - choose the best and easiest sampling location

4. Students should not wait around with nothing to do. There are enough experiments and equipment to keep them working. If an experiment is occupied, they should do another. The meter console and RM1 are always available if one of the others is full.

5. Students should not beat an experiment to death - collect the data and move on.

6. The molecular weight of dry air is 29 g/g-mole (lb/lb-mole). Less than 3% moisture can be considered dry air.

7. Pages 40 and 41 of the workbook should be completed. Page 41 is to be handed in on Wednesday morning.

LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: OPERATION OF THE ORSAT ANALYZER

COURSE: 450 - Laboratory 2
LESSON TIME: 1½ hours
PREPARED BY: Giuseppe J. Aldina
DATE: 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To familiarize students with the operation of the orsat analyzer and the calculation of stack gas molecular weight

Lesson Objectives:

The student should be able to

1. List the absorbing chemicals used in the orsat and the action of each
2. Perform a leak test on the orsat analyzer
3. Analyze a gas sample for CO_2, O_2, and CO using the orsat

Prerequisite Skills:

None

Level of Instruction:

College undergraduate science

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. 450 workbook page 66
2. 4 orsat analyzers

Special Instructions:

1. Leak check analyzers before class
2. Check reagent efficiency — it should not take more than 6-8 passes of air through the O_2 bubbler to show 20.9% O_2 in the air sample.

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References:

FR 8/18/78

Instructor:

Demonstrate orsat operation and explain bubbler chemicals

1. Chemicals

   A. Burette solution — Na_2SO_4 saturated H_2O with methyl orange on red indicator and H_2SO_4 to keep it acidic. The burette solution is made this way to keep stack gases from dissolving in it

   B. CO_2 Bubbler — 42-46% KOH or NaOH

   C. O_2 Bubbler — 42-46% KOH on NaOH and about 10-12 gms of pyrogallic acid (for 1 bubbler)

   D. CO Bubbler — Cuprous chloride (Cu^+Cl^-) dissolved in a solution that keeps a high hydrogen ion concentration such as acid or ammonia with some solid copper to maintain Cu ions in solution. This prevents oxidation of the solution before CO is bubbled through it.

2. Operation of the orsat

   A. Leak Test

      1. Use the burette solution as a sort of pump

      2. Fill the burette with the red solution

      3. Open the CO_2 bubbler and bring it to the reference mark

      4. Repeat for O_2 and CO bubbler

      5. Be sure all valves are closed

      6. Bring the burette solution to the mid point on the scale with the leveling bottle and solution at the same height — equal pressure on both sides. Record the reading chosen.

      7. Close the burette valve and set the leveling bottle on the table.

      8. After 4 minutes check all liquid levels. If the level drops find the leak.

B. Gas analysis

1. Carefully bring 100 cc of gas into the calibrated burette
2. Push the gas into the CO_2 bubbler then bring it back to the burette
3. Proceed carefully — do not mix the chemicals
4. After 3 passes read the CO_2 scrubbed by leveling the burette solution and leveling bottle.
5. Record the reading then confirm it by one more pass through CO_2 bubbler. Once is enough. If the reading is constant go on to O_2
6. O_2 — analyze as for CO_2 but
   a. allow the gas to reside longer in the bubbler
   b. make 6-8 passes before the first reading
7. CO is analyzed as for CO_2.

C. Calculations

$M_d = \Sigma M_x B_x$ (See RM3 lesson outline)

$$M_s = M_d (1-B_{ws}) + 18 (B_{ws})$$

COURSE 450

SOURCE SAMPLING FOR PARTICULATE POLLUTANTS
INSTRUCTOR'S GUIDE

WEDNESDAY LABORATORY
RM5 Testing

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LESSON PLAN

AIR POLLUTION TRAINING INSTITUTE

TOPIC: RM5 Testing

COURSE: 450 - Laboratory 3
LESSON TIME: 3 hours
PREPARED BY: G.J. Aldina DATE 10/2/78

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lesson Goal:

To give students practice in performing an RM5 source test.

Lesson Objectives:

The student should be able to:

1. Apply RM1 for particulate sampling and mark the sampling probe
2. Calibrate the sampling nozzle
3. Determine probe-pitot tube alignment in the sampling duct
4. Record RM5 data on appropriate forms
5. Assemble and disassemble RM5 equipment
6. Solve the isokinetic sampling rate equation using a nomograph or calculator
7. Operate the RM5 source sampling train
8. Analyze RM5 samples collected by these procedures
9. Make all calculations to determine RM5 pollutant emission rate

Prerequisite Skills:

Monday and Tuesday laboratory

Level of Instruction:

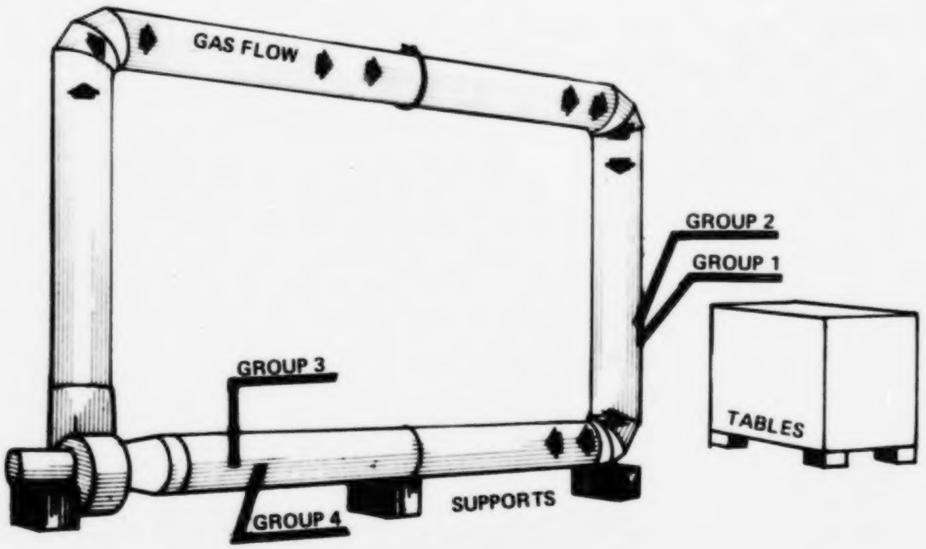
College undergraduate science

Intended Student Professional Background:

General Science

Support Materials and Equipment:

1. 450 Workbook, pages 82-93
2. Source Sampling Train
    a. Nozzle - to be calibrated before the test
    b. Pitot tube - calibrated by student group on Monday
    c. Probe
    d. Sample case and glassware
    e. Tared glass mat filter
    f. Umbilical cord
    g. Tools
    h. Meter console - calibrated by student group on Monday
3. 500 gm of fly ash
4. Laboratory duct
5. Tables and supports for placing sample trains into the duct. Use ports cut for Monday lab.


GAS FLOW
GROUP 2
GROUP 1
GROUP 3
TABLES
SUPPORTS
GROUP 4

Special Instructions:

1. Instruct students to organize their experiment properly before the laboratory following the lab exercise and flow charts.

2. Give the following assumed Orsat data and moisture estimate for the test, unless a real stack is being used, then give data for same, if known.

   CO_2 = 12.5%
   O_2 = 6.2%
   CO = 0.1%
   Approximate H_2O = 5%

3. Assemble the sampling trains for the students (they can get experience with hands-on while disassembling.)

4. Impingers and silica gel should be:

   a. 120 ml H_2O

   b. 100 ml H_2O

   c. Dry

   d. 200 gm silica gel

   but tell the students to assume that there is only 100 ml H_2O in each impinger (1 and 2) (if they sample about 30-35 cubic feet this will yield 3-5% moisture in the sample).

   If a real stack is being sampled, use 100 ml.

5. Analysis for the lab - students should:

   a. Weigh silica gel after the test

   b. Measure H_2O in the impingers

   c. Weigh the filter with the particulate catch

   d. Weigh probe wash after dried over-night. If this can't be done because of time, one of the instructors, or his assistant, should do it and provide students with the data.

References

Federal Register - Vol. 42, No. 160, August 18, 1977. "Standards of Performance for New Stationary Sources - Revision to Reference Methods 1-8.

Instructors should:

1. Encourage students to work out their own sampling team assignments
2. Read the lecture and laboratory exercises
3. Be available for questions and to help students perform the test
4. Check student calculations of K or nomograph settings
5. Work out with students how sampling will be done. Suggested method is to have one team start at the far points in the duct and work outward while the other works its way in. This has proven good practice in past courses.
6. Try to put the equipment on separate electrical circuits to prevent power outrages. If the load frequently trips the circuit breaker turn off the probe and filter heaters in the trains
7. Add fly ash to the duct in small amounts until several hundred grams have been fed in. One way of adding the fly ash is to punch a hole in the duct, and supply the ash using a funnel or some other apparatus. Note: Don't add too much or it might start leaking out of the cracks in the duct. The concentration of particulate can be approximated from the weight added to the duct and the volume of ductwork system.

Method 5 Particulate Test
Calculation Form

I. Neccessary Data

A. Reference Method #1

- Area of stack _____ ft^2
- No. of equivalent diameters upstream ________
- No. of equivalent diameters downstream ________
- No. of traverse points _______
- Total test time (θ) _______ minutes

B. Reference Method #2

- Average stack temperature T_s _____ °F + 460 = ______ °R
- Stack absolute pressure ______ in. Hg.
- Barometric Pressure ______ in. Hg.
- $\left(\sqrt{\Delta p}\right)_{ave}$ ______ (in. $H_2O)^{1/2}$

C. Reference Method #3

- $\%CO_2$ ______; $\%O_2$ ______; %CO ______ ; $\%N_2$ ______

D. Reference Method #4

- Water collected
  - Impinger H_2O ____ ml
  - Silica Gel ____ gm

E. Reference Method #5

- Area of nozzle _____ ft^2
- Average ΔH _____ in. H_2O
- Average meter temperature T_m ____ °F + 460 = ______ °R
- Dry gas meter correction factor _____.
- Volume metered V_m = _____ CF
- Particulate Weight _____ gm

II. Calculations

A. Standard Volume Metered Y Dry Gas Meter calibration factor

$$V_{m(std)} = V_m Y \frac{T_{std}}{P_{std}} \left(\frac{P_b + \frac{\Delta H}{13.6}}{T_m}\right)$$

$$V_{m(std)} \quad (\qquad \text{CF}) \left(\frac{528\,°R}{29.92 \text{ in. Hg}}\right)\left(\frac{\_\_\_\_\_\_ \text{ in. Hg}}{°R}\right) = \_\_\_\_\_\_ \text{ dscf}$$

B. Moisture Content of Stack Gas

1. H_2O collected in impingers in standard cubic feet

   $V_{wc(std)} = K\,(V_f - V_i)$

   $V_{wc} = 0.04707\ \text{ft}^3/\text{ml}\ (\underline{\qquad}\ \text{ml}) = \underline{\qquad}\ \text{scf}$

2. H_2O collected in silica gel in standard cubic feet

   $V_{wsg(std)} = K\,(W_f - W_i)$

   $V_{wsg(std)} = 0.04715\ \text{ft}^3/\text{gm}\ (\underline{\qquad}\ \text{gm}) = \underline{\qquad}\ \text{scf}$

3. Moisture content of stack gas (B_{ws})

$$B_{ws} = \frac{V_{wc(std)} + V_{wsg(std)}}{V_{wc(std)} + V_{wsg(std)} + V_{m(std)}}$$

$$B_{ws} = \frac{(\underline{\qquad}\ \text{scf}) + (\underline{\qquad}\ \text{scf})}{(\underline{\qquad}\ \text{scf}) + (\underline{\qquad}\ \text{scf}) + (\underline{\qquad}\ \text{scf})} = \underline{\qquad}$$

C. Molecular Weight of Stack Gas (lb/lb-mole)

1. M_d (Dry molecular weight) = $\Sigma M_x B_x$

   $M_d = (.44)\ \underline{\qquad}\ \%CO_2 + (.32)\ \underline{\qquad}\ \%O_2\ +$

   $(.28)\ \underline{\qquad}\ \%CO + (.28)\ \underline{\qquad}\ \%N_2 = \underline{\qquad}\ \text{lb/lb-mole}$

2. M_s (Wet Molecular Weight) = $M_d(1 - B_{ws}) + 18\ B_{ws}$

   $M_s = \underline{\qquad}\ (1 - \underline{\qquad}\ ) + 18(\underline{\qquad}\ ) = \underline{\qquad}\ \text{lb/lb-mole}$

D. Average Stack Gas Velocity

$$\overline{v}_s = K_p C_p \sqrt{\frac{T_s}{P_s M_s}}\left(\sqrt{\Delta p}\right)_{ave}$$

$$\overline{v}_s = 85.49\ \text{ft/sec}\left(\frac{\text{lb/lb-mole (in. Hg)}}{°\text{R(in.}H_2O)}\right)^{1/2}\underline{\qquad}\ \sqrt{\frac{(\qquad\qquad)°\text{R}}{(\qquad\ \text{in. Hg})(\qquad\ \text{lb/lb-mole})}}$$

$$\sqrt{\underline{\qquad}\ \left(\text{in. } H_2O\right)}\qquad \underline{\quad}\ \text{ft/sec}$$

E. Average Stack Gas Volumetric Flow Rate

$$Q_s = (3600\ \text{sec/hr})(v_s)(A_s)(1 - B_{ws})\ \frac{T_{std}}{P_{std}}\ \frac{P_s}{T_s}$$

$$Q_s = (3600\ \text{sec/hr})(\underline{\qquad}\ \text{ft/sec})(\underline{\qquad}\ \text{ft}^2)(1 - \underline{\qquad}\ )\ \frac{528°\text{R}}{29.92\ \text{in. Hg}}\ \frac{\underline{\qquad}\ \text{in. Hg}}{\underline{\qquad}\ °\text{R}}$$

$Q_s = \underline{\qquad\qquad}\ \text{dscf/hr}$

F. Pollutant Mass Rate

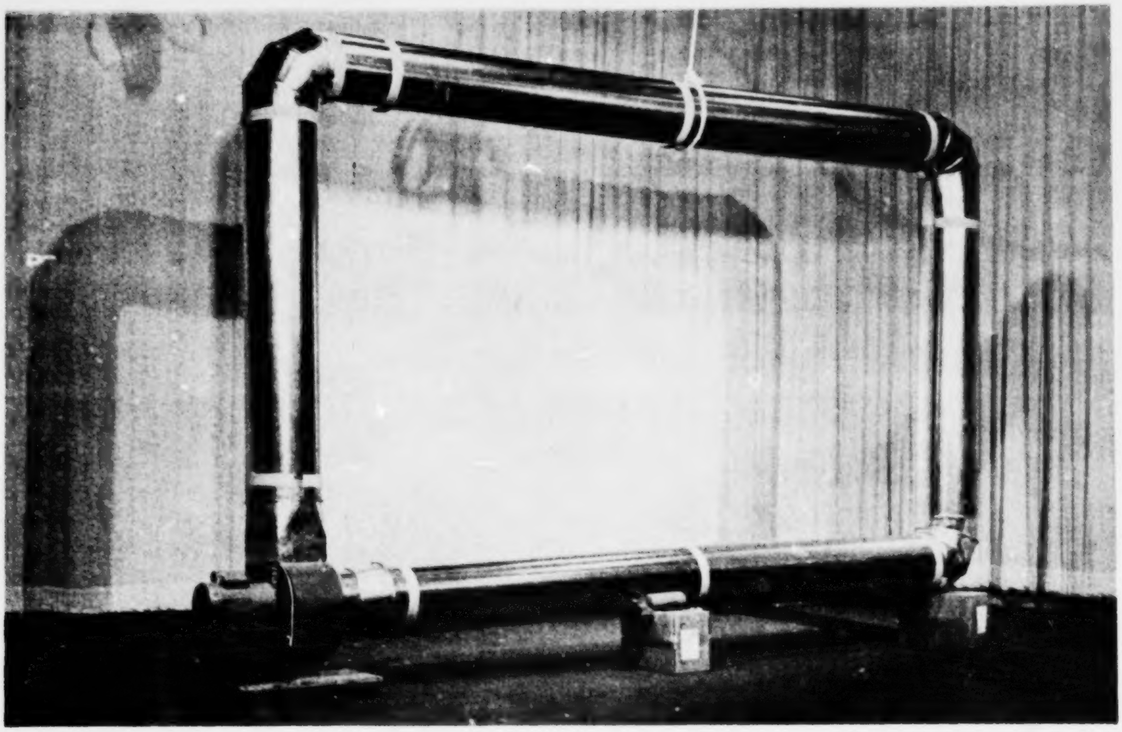
$$\text{PMR} = \frac{\text{mass}}{V_{m(std)}} \times Q_s$$

$$\text{PMR} = \frac{(\underline{\qquad\qquad})\text{gm}}{\text{dscf}} \times \underline{\qquad\qquad} \text{ dscf/hr} \times \frac{1}{454 \text{ gm/lb}} = \underline{\qquad\qquad} \text{lb/hr}$$

G. %Isokinetic Variation (Intermediate Data)

$$\%\text{I} = \frac{T_s V_{m(std)} P_{std} 100}{A_n \theta v_s P_s T_{std} 60(1 - B_{ws})}$$

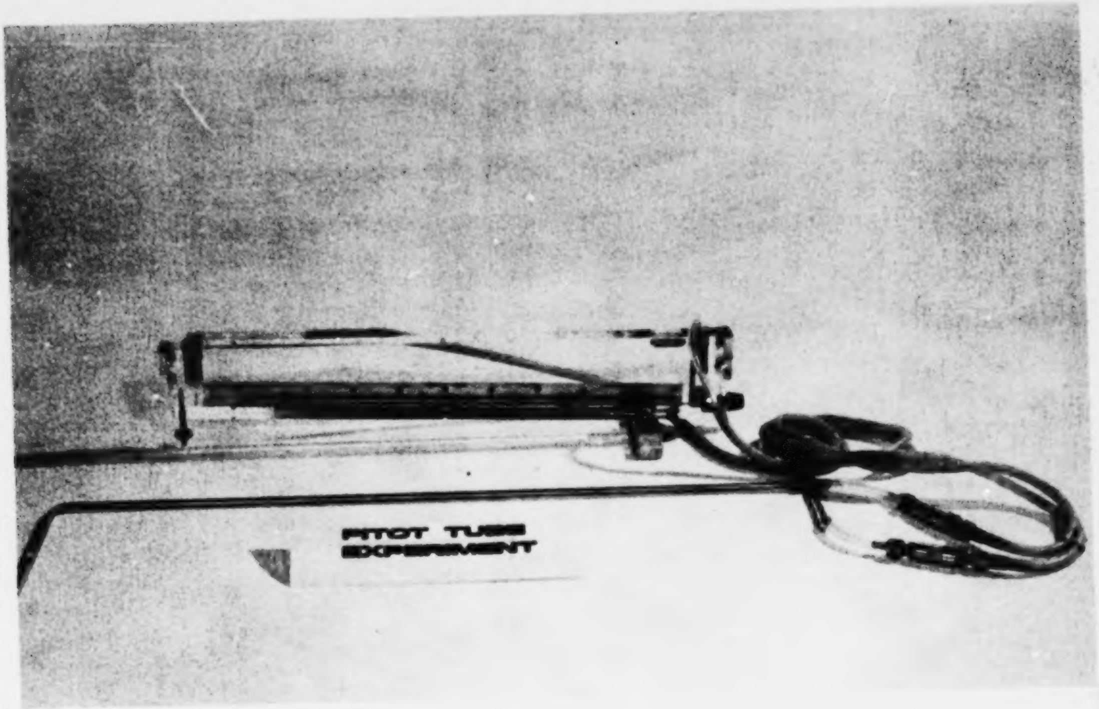
$$\% = \frac{(\underline{\qquad\quad}{}^\circ\text{R})(\underline{\qquad\quad}\text{dscf})(29.92 \text{ in. Hg})}{(\underline{\qquad\quad}\text{ ft}^2)(\underline{\qquad\quad}\text{min})(\underline{\qquad\quad}\text{ ft/sec})(\underline{\qquad\quad}\text{in. Hg})(528{}^\circ\text{R})(60 \text{ sec/min})(1 - \underline{\qquad\quad})}$$



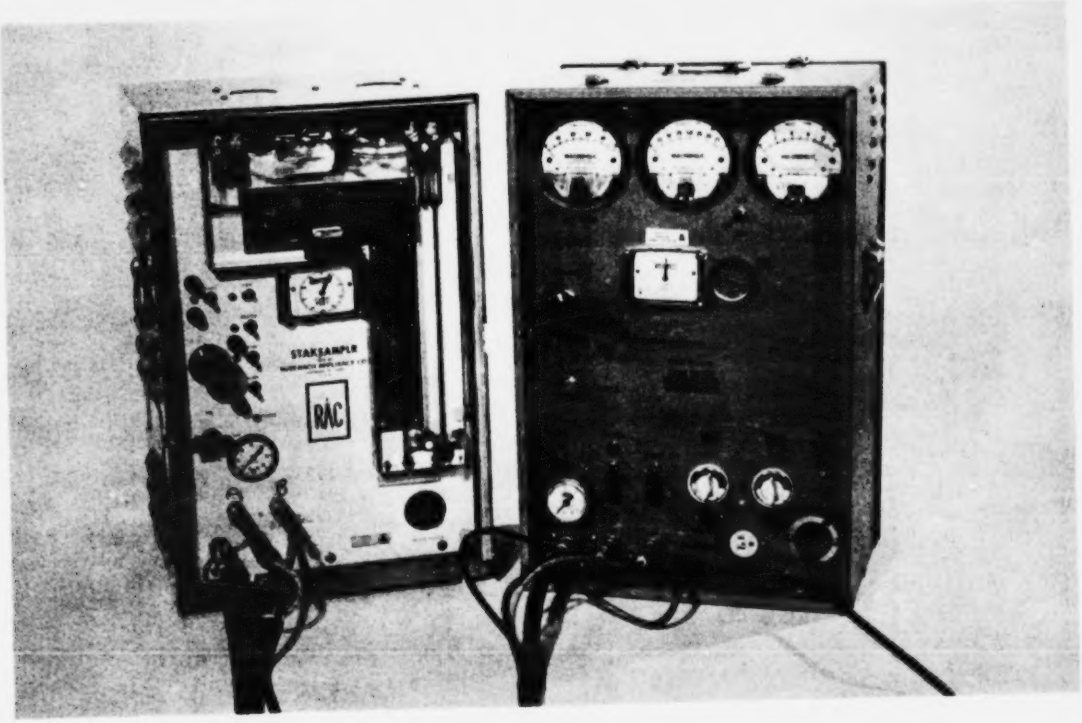
Assembled sampling duct constructed of 12 inch galvanized ductwork
Laboratories 1 and 3

WET BULB-DRY
BULB EXPERIMENT

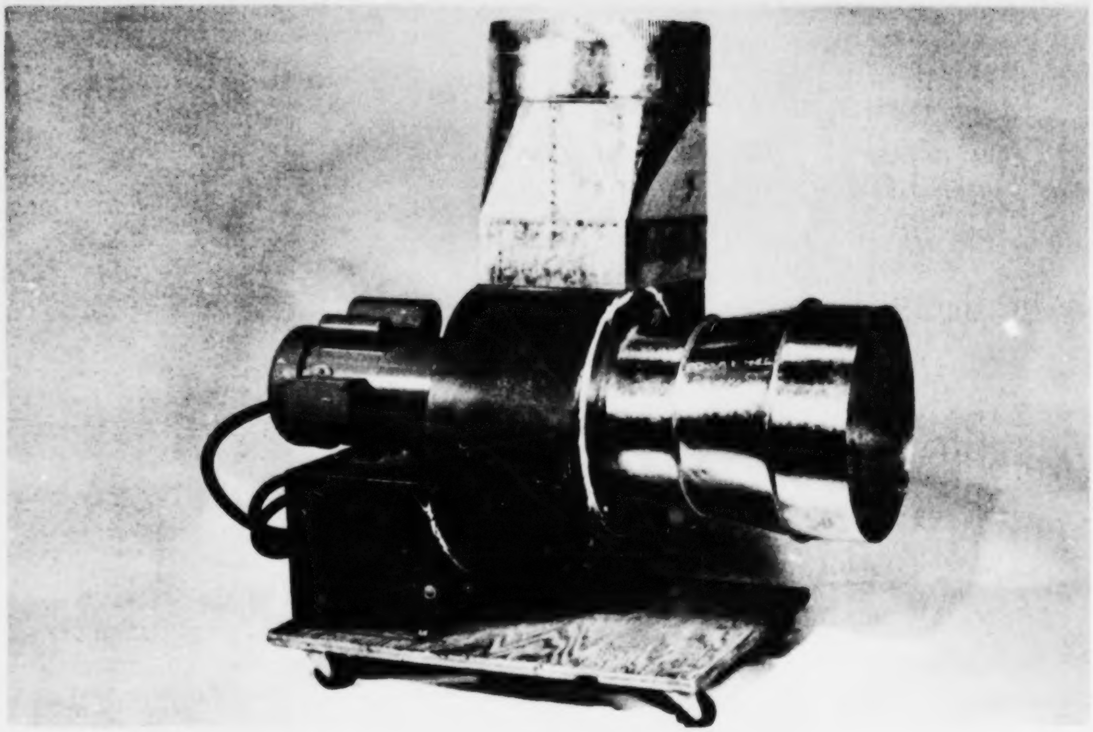
Apparatus for Wet Bulb-Dry Bulb moisture estimation experiment


PITOT TUBE
EXPERIMENT

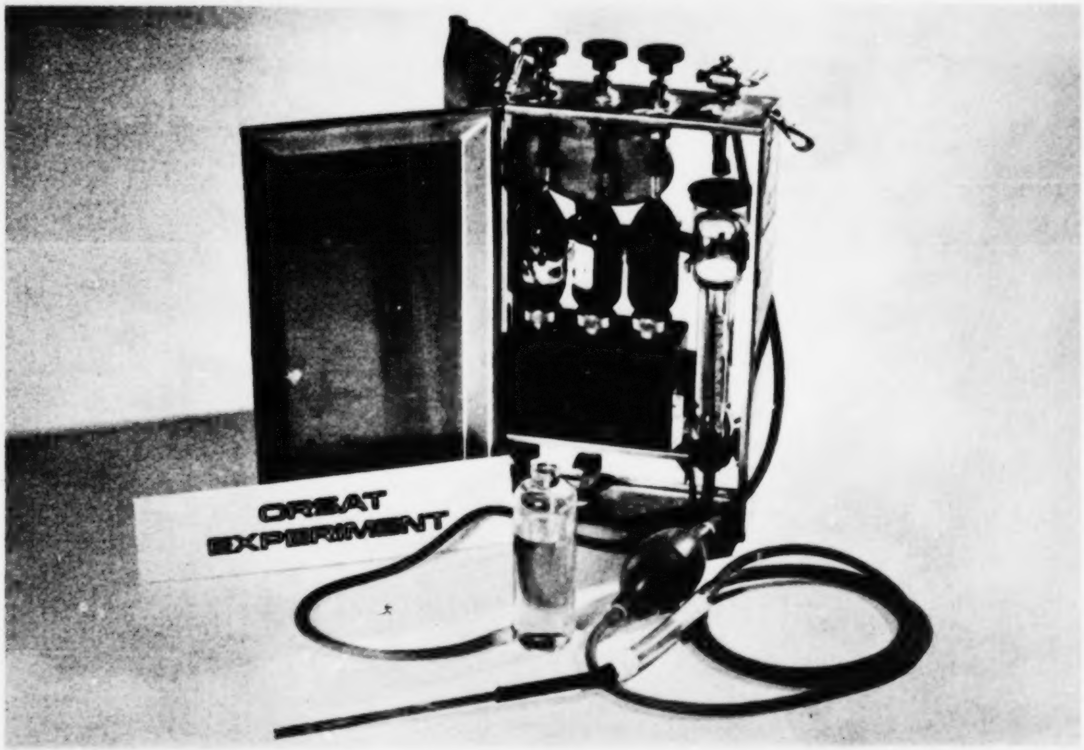
Inclined oil manometer and Prandtl tube for calibration of the Type S pitot tube


STAKSAMPLR
RAC

RAC (left) and Nutech (right) Meter Consoles

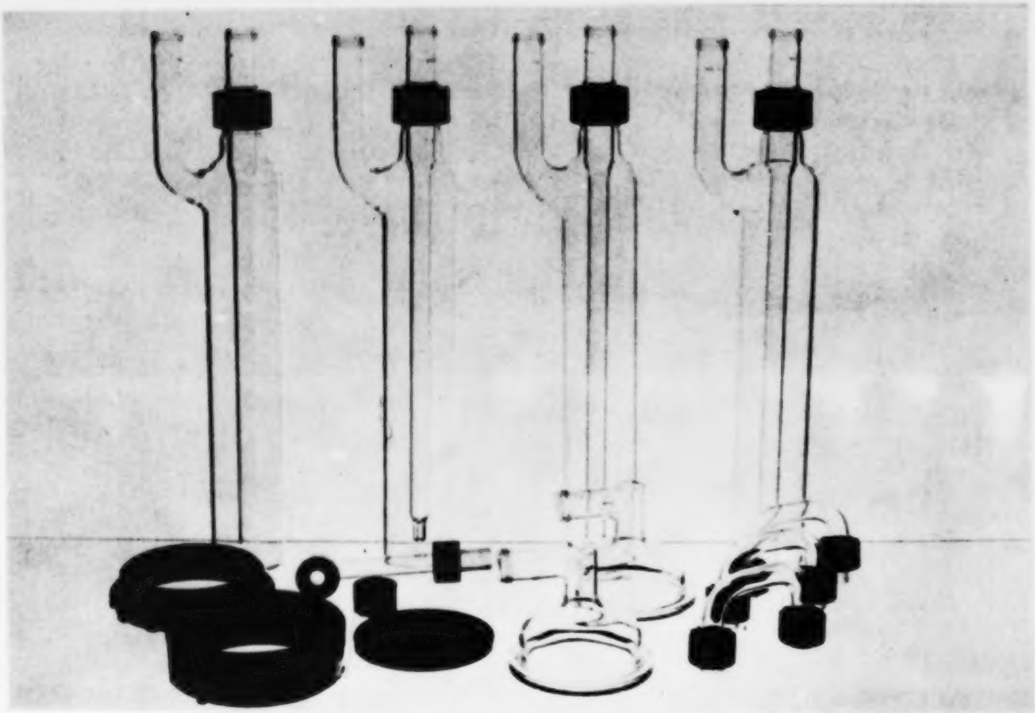


Blower section for sampling duct

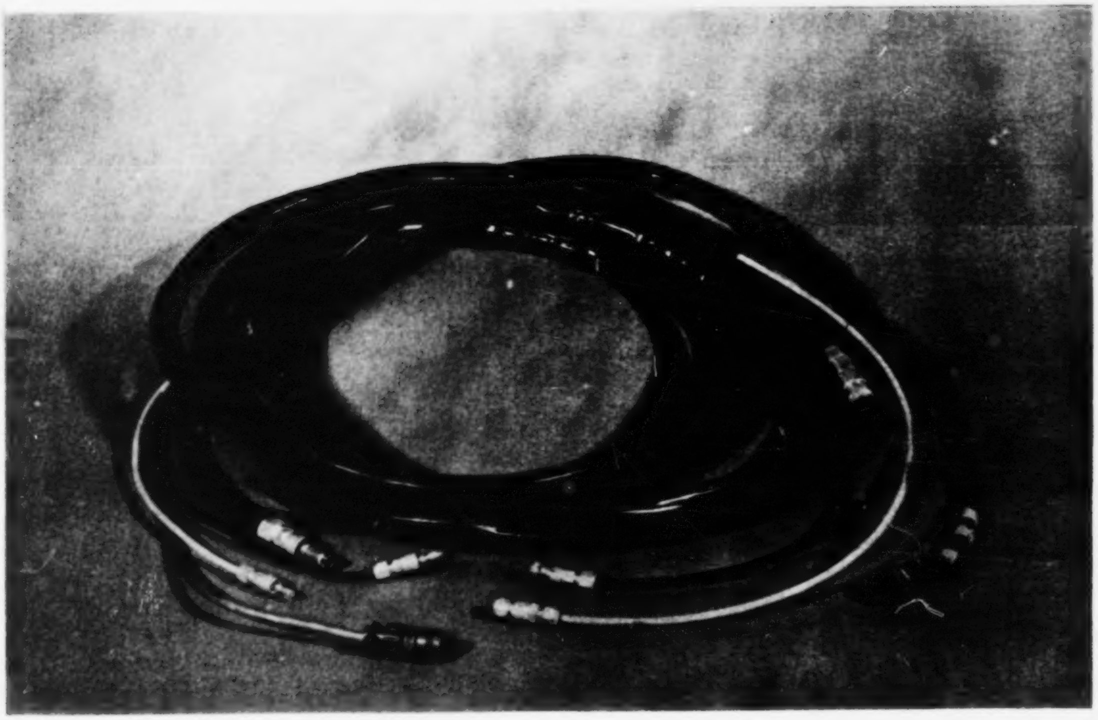


ORSAT
EXPERIMENT

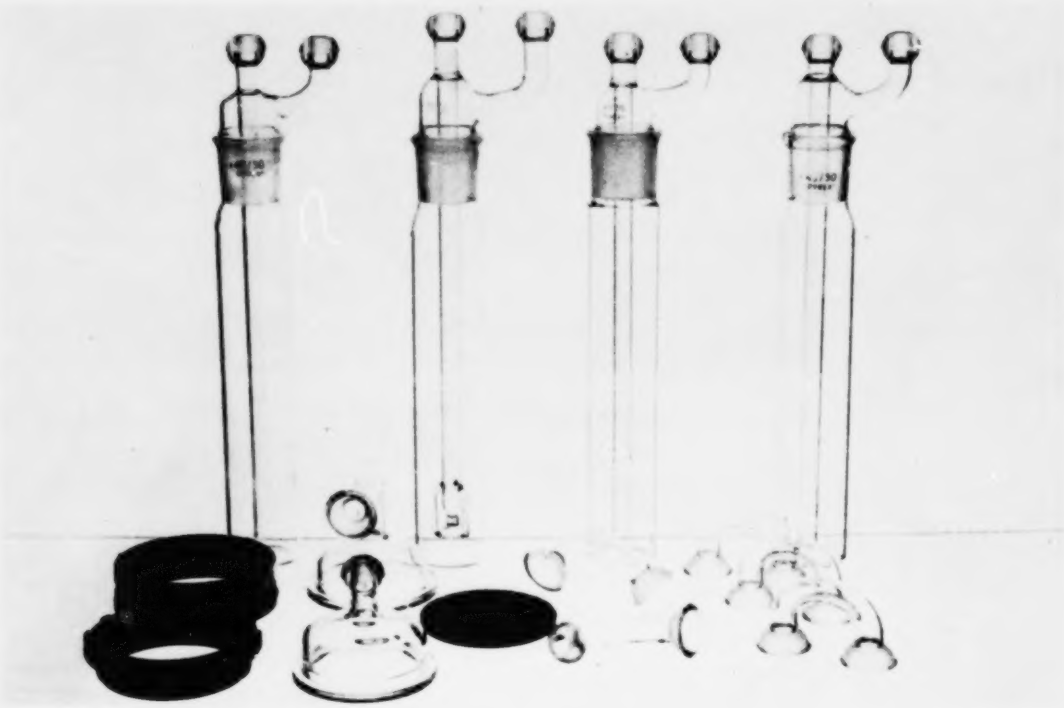
Hayes Orsat



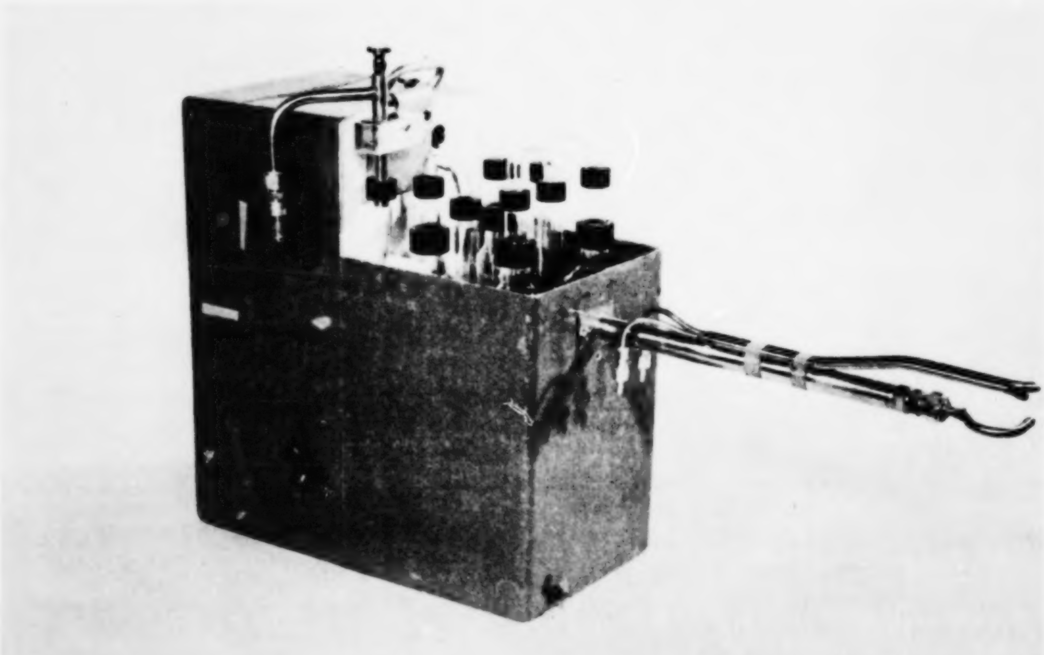
Screw-joint compression seal glassware



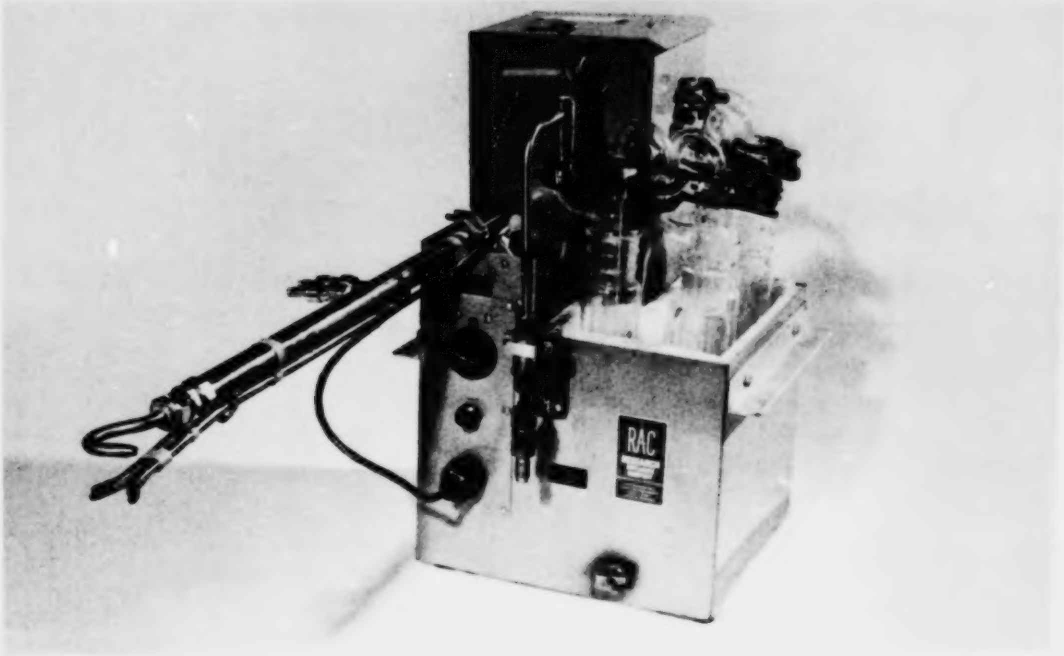
Umbilical Cord



Ground glass ball-joint glassware



Nutech Sample Case with glassware and sampling probe



RAC Sample Case with glassware and sampling probe

HANDOUTS FOR COURSE 450

SOURCE SAMPLING FOR PARTICULATE POLLUTANTS